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ROAD AND FOOTPATH CONSTRUCTION

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Edited by PAUL N. HASLUCK.

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ROAD AND FOOTPATH CONSTRUCTION

Macadamised Roads;
Stone, Wood, and
Asphalt Paving;
Footpaths

Edited by
PAUL N. HASLUCK
Editor of "Work," "Building World," etc.

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PREFACE.

THIS Manual contains, in form convenient for everyday use, a comprehensive digest of the knowledge of Road and Footpath Construction scattered over eighteen volumes of BUILDING WORLD—one of the weekly journals it is my fortune to edit.

It may be mentioned that a number of articles by Mr. Arthur Bowes, A.M.I.C.E., Surveyor to the Council of Newton-in-Makerfield, have been incorporated in the text.

Additional information on the matters dealt with in this Manual, or instruction in kindred subjects, may be obtained by addressing a question to BUILDING WORLD, in whose columns it will be answered.

P. N. HASLUCK.

La Belle Sauvage, London,
August, 1904.

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ROAD AND FOOTPATH CONSTRUCTION.

CHAPTER I.

INTRODUCTION; FOUNDATIONS FOR MACADAMISED ROADS.

It is only within the last century that systematic attention has been given to the proper construction of highways, which is now regarded as being one of the most important duties of local governing authorities. The first twenty years of the nineteenth century witnessed a great advance in ideas concerning the subject; and the nation is indebted to Mr. J. L. Macadam for persistence in advocating his views and for much expenditure of time and money, although the methods which he advocated were not those now in vogue, nor were they novel.

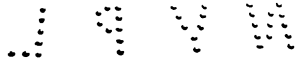
Macadam taught that, instead of heaping up boulders, mud, brushwood, or any kind of rubbish just where the roadway was worn away, the whole surface of the road, after being carefully trimmed to its proper shape, should be covered with a layer of small angular stones, so that, when crushed together by traffic, they formed a hard, compact skin, protecting the underlying earth and providing a fairly smooth surface. He contended—(1) That a foundation or bottoming of large stones is unnecessary and injurious on any kind of subsoil. (2) That the strength or depth of "metal" requisite for any road is only 10 in. (3) That the duration only, and not the condition, of a road depends upon the quality and nature of the material used. (4) That freestone will make as good a road as

any other kind of stone. (5) That it is of no consequence whether the substratum be soft or hard. No road-surveyor to-day agrees with these views.

Thomas Telford, at that time Engineer to the Commissioners of Highland Roads and Bridges, first put into practice the principle of modern road construction, namely, that of providing a solid foundation, a principle directly opposed to the first and the fifth of the statements of Macadam. Time has shown the value of Telford's methods.

With regard to route and inclination, the ideal road, from the practical point of view, is that which connects two points in the straightest direction and is nearly level throughout its entire length. Such an ideal, is not, however, likely to be realised in any except very short roads. There are often so many considerations of varying level in the ground, and there is the cost of disposing of excavated material, or the desirability of approaching some intermediate point, that the preliminary determination of the route of a new road of any extent is a matter calling for much judgment and entailing a great many compromises between the desirable and the practicable.

In laying out a new road, a map or survey of the land to be traversed has to be examined, and information as to the levels is obtained. If the levels are connected up so as to form contour lines, any route lying parallel to the contours will, of course, show how the road may be laid out without gradient; but, generally, some deviation will be necessary. If the roads are merely short, cutting up an estate into building blocks, their course will be governed generally by the size of plots required and the necessity of making them of good shape for building purposes. Where land is valuable, the roads are laid out to absorb as little of the land as possible. It is economical to choose a route *that will enable* the earth excavated in one por-



tion to be used for filling up depressions in other parts, thus lessening the cost of carting materials.

An absolutely level road is very fatiguing to horses, and is not to be desired; while a slight inclination or gradient in the length, and a fall from the middle to the sides, assists the rain to run down instead of sinking into the surface. Steep gradients are, of course, to be avoided as far as possible, on account of the difficulty of traversing them with heavy loads. Telford, as the result of experiments on the power of horses in pulling loads, laid down the rule that a main road should not have steeper gradients than 1 in 30, while Sir John McNeill, a pupil of Telford, adopted 1 in 40 as the gradient not to be exceeded, and adduced as argument in favour of this view that a steeper gradient would be found to cost more in repairs through the heavier action of the horses' feet upon it and the injury done by skidded wheels.

When the direction of the roads has been finally decided upon, it will be necessary to set out on the ground some guide to the workmen. The usual plan is to set out the centre lines of the roads by the ordinary methods of surveying—into which this work will not enter—and then to drive short stakes into the ground at regular intervals along the centre of the proposed roads. Afterwards a "grip" or small channel is cut along the centre-line from stake to stake, and from the line thus indicated it is an easy matter to set off the lines of the kerbs or of the buildings. The levels also of the formation, showing the workmen to what depth the excavation or filling has to be carried, will be set out by the surveyor, and fixed points provided where changes of gradient occur, so that by means of "boning rods" the levels can be carried through between these points at an even *gradient.*

Great care has to be exercised in keeping the foundations of a road as dry as possible. The upper surface, formed of hard macadam and consolidated by rolling, should be practically impervious to water, and the same care must be displayed in getting rid of water in the substratum. This is done by laying rough drains across the width of the road at intervals which vary according to the nature of the earth. The drain may be formed of strong agricultural drain-pipes, but, on account of the liability of these to be broken by heavy traffic, it is preferable to form the drain of bricks surrounded by broken stones, as shown in Fig. 1, or the stones alone will form an efficient

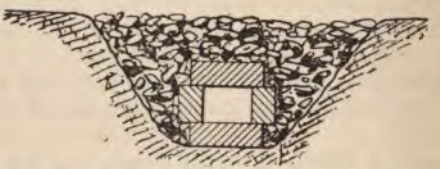


Fig. 1.—Under-drain Made with Bricks.

drain. When there is a longitudinal fall in the road, the cross-drains should be inclined from the centre of the road in the direction of the fall, and should discharge into side drains or open ditches. This arrangement is shown by Fig. 2, the arrow indicating the direction of the fall of the road.

Where the road is constructed on the side of a hill, a side drain should be formed on the upper side of the road, to intercept any water which may drain down from the hill, otherwise the foundations will be kept in a continual state of moisture. A roadway which is subject to the influence of sunlight is easier to keep in good repair than one which is kept damp by the presence of trees or high buildings along its borders.

In order that rainwater falling upon the surface

of a road may not soak into the foundations, it is necessary to provide a certain amount of fall from the centre of the road to the sides, by which means the water runs down into the side channels. The amount of this "cross fall," as it is called, varies with the nature of the road covering, as well as with the opinions of the road surveyor.

The Model Bye-laws issued by the Local Government Board, in connection with the Public Health Act of 1875, recommend that a rise of $\frac{1}{8}$ in. to $\frac{3}{4}$ in. per foot be given from the sides to the centre of the road, or for every foot in the half-width of such carriageway. For a roadway 24 ft. wide between the footpaths, the rise in the centre, accord-

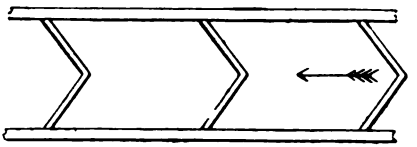


Fig. 2.—Inclined Cross-drains for Road with Gradient.

ing to this rule, would be from $4\frac{1}{2}$ in. to 9 in. The larger amount is somewhat excessive, except where the roadways are made of very soft materials, allowing the water to soak in very quickly; the lesser allowance is more in accordance with general practice. Rankine says that from 4 in. to 6 in. is sufficient.

In specifications for this class of work, a usual clause is that the cross fall shall be at the rate of 1 in 30; this gives a rise of rather more than $4\frac{3}{4}$ in. in a roadway 24 ft. wide. As the surface will become consolidated in time through the passing traffic, the rise may, with advantage, be made a trifle higher than this, so as to allow of its settlement down to this level. Formerly roads were made much more rounding on the surface than the above proportions, but if the road is very

much arched, its centre is the only place where vehicles can travel without tilting to one side, and the result is that all the traffic passes over one part of the road, thereby causing it to wear into ruts, in which water is imprisoned.

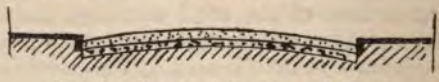


Fig. 3.—Rounded Surface of Road.

A longitudinal fall, or fall in the length of a road, is much more effectual in removing water than is a cross fall, for the ruts caused by the wheels of vehicles act as gutters, and carry the water down to the lowest point. A longitudinal fall is, therefore, always desirable, enabling the road to be made flatter in cross-section and more convenient for traffic.

Specifications usually provide that the sides of the road should slope from the centre in straight lines, and that these straight sides should be joined at the centre by a curve of large radius. On the other hand, it is sometimes specified that the surface should be formed to one circular arc of large radius, as shown in Fig. 3. It does not matter which system is followed, for, after the

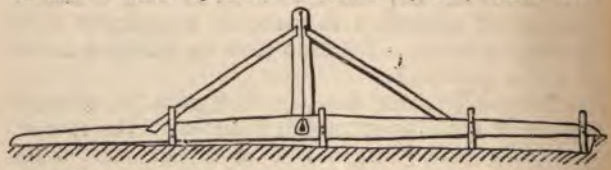


Fig. 4.—Adjustable Gauge for Surface Contours.

road has been in use a few weeks, the surface will probably have lost such refinements of contour. In the setting out of these surface levels, special instruments have been adopted, such as those shown in Figs. 4 and 5, which will be self-explana-

tory. The usual practice is simply to calculate the rise in the middle of the road, and to drive in a peg at that point with a mark upon it, to indicate the finished level. Similar pegs mark the finished level at the kerbs, and other intermediate pegs may be provided if thought necessary; or the correct batter of the road may be found by "boning."

The efficiency of a road depends upon the quality of the materials and workmanship put into the part that is not seen—the foundation. No matter how good the surface of the road may be, or how carefully constructed, if the bottom is not hard and solid enough to bear the weight imposed

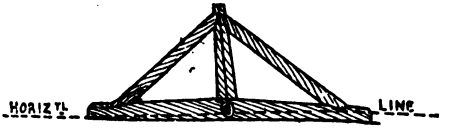


Fig. 5.—Fixed Gauge for Surface Contours.

upon it by traffic, depressions will be caused in the surface, where water will collect; this will gradually soften and disintegrate the materials, causing them to wear away quickly.

The foundation, when once put in, should never require to be touched again. It should be formed of such materials, and be so consolidated, that it will maintain its form under the heaviest traffic for all time; and the best foundation will ultimately prove to be the cheapest. The natural formation of the country through which the road passes will, of course, determine the class of earth or rocks of which the bottom of the road is formed. Clay soils, although capable of carrying great weight, are liable to expand under the influence of water and frost, and every means must be taken to keep them well drained. Chalk also has a tendency to absorb moisture, which expands under

frost and forces the chalk into small fragments. Gravel or sand and gravel mixed forms as good a natural formation as it is possible to get, being solid and firm under pressure, and not liable to hold water in suspension.

In forming the foundations, the surface is excavated to a depth of from 12 in. to 15 in. below the level at which it is intended to form the surface of the road. In the best practice, the surface of this excavation will be curved in the same manner as the finished surface, so that an equal thickness of road ballast (see Fig. 6) will be deposited over the whole width of the road. Sometimes, however, the surface of the excavation, or "road bed," is made level, so as to require a greater thickness of ballast in the middle, where, it is argued, the traffic will be greater than at the sides; this method of construction is shown by Fig. 7.

For the ballasting or "bottoming" of the road, a 6-in. layer of concrete composed of one part of Portland cement to six parts of gravel or broken stone, is best. Unfortunately, the cost of this prevents its general adoption. If, as is usually the case, a stone formation is adopted, Telford's method gives the best results. This consists in setting by hand a rough pavement of stones of moderate size, usually from 6 in. to 8 in. wide, and from 12 in. to 15 in. long. These are placed on edge, close together, in parallel lines, breaking joint wherever possible. When the whole width of the road has been laid with these rough stones, a "pinch bar" or iron crowbar is inserted, and the stones are forced still closer together, other stones being packed in to make as tight a job as possible. The interstices are then filled in with small chippings, and the whole surface is rammed down. As a final dressing, any portions of stone *which project* much above the general surface are

ocked off with a hammer. This stone "bottom-," or "pinning," as it is sometimes called, ould be from 6 in. to 9 in. thick, according to

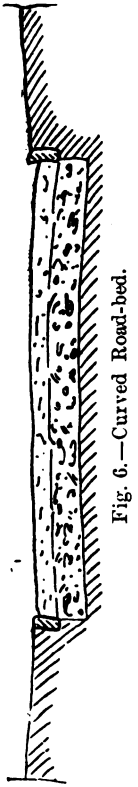


Fig. 6.—Curved Road-bed.

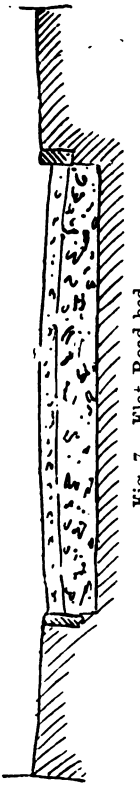


Fig. 7.—Flat Road-bed.

e amount of weight that will come upon the ad.

When stone is not obtainable, the foundations e formed of other materials. In the neighbour-*od of ironworks*, a good material is the slag

from the furnaces, while, in other parts, "hard core" of broken bricks and other refuse—too often of an inferior nature—is used. In agricultural districts a ballast is made by burning clay until it vitrifies and will break up like brickbats. If a suitable clay is used, and the burning properly carried out, a good material is obtained in this way.

When a road is carried through a soft, boggy district, where no firm foundation can be secured, as is the case in many parts of Ireland, a deep ditch is dug on each side of the intended road, and left for some months—perhaps a year—until the track between them has been drained as much as possible. Then turf, cut from some other portion of the bog, is piled upon the road and compressed to form a tough, elastic foundation on which to lay the upper formation of stone. Care is taken not to disturb the turf immediately adjoining the roadway on either side, for, if the turf is removed, the soft earth has a tendency to be forced upwards by the weight of the road and the traffic on it.

In very bad cases, where the ground is swampy, bundles of brushwood, called fascines, are laid on the intended road, and serve to spread its weight over a larger area of the soft ground. These fascines are usually about 1 ft. in diameter and perhaps 20 ft. long, and they are laid alternately lengthways and crossways on the bed of the road and are fastened together with wooden stakes.

CHAPTER II.

MACADAMISED ROAD MAKING.

THE qualities most essential in the materials used for the final covering of the road are hardness and toughness, and the stones most suitable for this purpose are the granites, syenites, basalts, traps, and whinstones. A stone may be very hard, and yet be unsuitable for road covering on account of its friability, as, for example, the flint, which is very brittle and will grind into a powder under traffic. Igneous and siliceous rocks generally do not bind well, while limestones bind but are too readily affected by water. Amongst the best known granites used for macadam are those from Aberdeen, Dartmoor, Guernsey, and North Wales.

Before being used, the stone is broken up by hand or machinery into angular pieces as nearly cubical as possible and of certain specified gauges, or sizes, usually 2½ in. or 2 in. That is to say, a stone broken to a 2-in. gauge must be capable of passing through a ring 2 in. in diameter, in any direction. The angularity of the stones is of great importance, as it is on this condition that the power of interlocking or binding with the adjoining stones depends.

In addition to the gauge of 2 in., it is sometimes specified that no single stone shall exceed 6 oz. in weight, and Mr. Macadam used to remind the workmen that any stone which they could not put easily into their mouths was too large and must be broken smaller. The harder qualities of stone should be broken smaller than those of a softer nature.

In the choice of material, financial considerations have an influence, of course, and very often inferior qualities of stone will have to be used because the cost of transit would make the better quality too expensive.

Practice varies somewhat in different districts with regard to the thickness of metalling laid on the road, but, as a general rule, the material is deposited in two layers, the lower layer being composed of larger stones than the top one. Sometimes three separate layers are employed. In all cases it is desirable that the steam roller should be passed backwards and forwards over the metal until it is thoroughly consolidated, as will be described later. The total thickness of metalling laid may vary from 4 in. to 7 in. or 8 in. In all cases the contour or cross section of the surface of the road is to be carefully regulated as described on p. 14.

The necessity for the use of some binding material, such as sand sprinkled on the road, has been a source of much difference of opinion. Macadam held that no such material was necessary, and that the broken stones, if of proper shape and thoroughly rolled, would consolidate themselves into a hard, compact mass impervious to water; while, on the other hand, Telford, in constructing his main roads through the Highlands, adopted a binding coat of 1 in. of fine gravel. Though some surveyors agree with Macadam on the point, it is indisputable that the use of binding when properly applied is an advantage; the French road engineers use binding material for the macadamised roads of France, which are admitted to be the best in the world. In France a proportion of binding material equal to one-fourth of the metalling is allowed, while in Hanover the proportion is one-sixth. The materials used may consist of sand, fine gravel, or gritty road scrapings, but should

be quite free from earthy material. Roads formed with a metalling of limestone require a binding of gravel or flint, while flint roads require a small proportion of limestone or chalk to assist consolidation. It is important that only a very small proportion of binding material should be mixed with the metal before rolling; after the metalling has been made compact and solid by rolling, then a coating of binding may be applied.

Mr. Thomas Aitkin recommends that the binding material, preferably loamy sand, be placed along the water tables or channels of the road during the watering and rolling of the surface. The water which runs down into the channels forms a kind of thin mortar with the sand, and this should be swept by hand over the whole surface of the road from the sides to the centre, filling the voids until the whole coating is consolidated by rolling, and presents a mosaic-like appearance. In breaking up a portion of a road formed in this way, he found the proportion of binding material to be barely 15 per cent., or less than one-sixth, of the bulk of the material. As to the materials used for binding, he says:—"Heavy and argillaceous soils should be avoided. They absorb and retain a considerable amount of moisture, which acts adversely on the surface under varying conditions of weather. Clean sand is also unsuitable; it has not sufficient cohesive properties to retain the metal in position, and is liable during watering to be washed to the bottom of the metal coating, from which it cannot be recovered, and forms what is termed a 'rotten' road."

With regard to rolling, it may be said that one of the first English engineers to use and recommend it was Sir John F. Burgoyne, chairman of the Board of Works in Ireland. Naturally, the first rollers were drawn by horses; some were of stone, some were cast-iron rollers lagged with

wood, some were hollow cylinders made for holding water; others, again, were sheet iron cylinders filled in with cement. In 1866 Messrs. Easton, Amos & Anderson used one of Aveling & Porter's traction engines for drawing a 10-ton roller, and the expedient was fairly successful. Messrs. Aveling & Porter thereupon devised a combined traction engine and roller, very much on the lines of those now made by the same firm, and in 1867 they supplied a 30-ton steam roller to the Corporation of Liverpool. This is much in excess of what is usually employed at the present time. In most cases a 10-ton or 15-ton roller is preferred, in order to minimise the danger of damaging gas-pipes, water-pipes, and sewers under the road being rolled. A steam roller weighing eight tons will roll a width of 4 ft. 9 in. at once; ten tons will roll 6 ft. 3 in.; twelve tons will roll 6 ft. 6 in.; fifteen tons will roll 7 ft. 3 in.; twenty tons will roll 8 ft. 3 in. wide. That the use of the steam roller reduces the cost of maintaining a road in good condition is generally admitted.

A steam roller can be used on inclines as steep as one in seven, and besides its ordinary use as a roller it can be adapted to "picking up" a roadway preparatory to laying fresh metal, or it can be employed in driving one of the stone-breaking machines used for preparing new macadam.

It cannot be insisted upon too often that no binding material should be applied to the road before the roller has been passed several times over the newly laid stones in order to force them into as close contact as possible. The use of the binding is to fill in interstices remaining after the interlocking of the metalling, and any hard substance, such as gravel, applied to the road while the metalling is in a loose condition, can only tend to prevent the roller doing its work effectually.

Unless there has been a slight fall of rain, it

will be necessary to water the roadway before the roller is passed over it; but too much water must not be used, or the gravel and sand will adhere to the surface of the rollers. The sides of the road must be rolled first so that they can offer resistance to the spreading of the material when the middle comes to be rolled. The amount of rolling required depends largely upon the quality and thickness of the metalling and the standard of perfection required by the road surveyor. In the construction of the French highways, it is not unusual for the rolling to be continued until a cubic inch of hard macadam material laid on the finished surface of the road is crushed by the roller without being pressed into the finished surface or injuring its compactness. It is doubtful if any English roads have been brought to such a degree of excellence.

The amount of work that can be done with a steam-roller in a day naturally varies with the thoroughness with which the work is done, the size and quality of the stone, and the class of work in hand, whether only small detached portions of roads, or jobs large enough to keep the roller going for several days together. If the roller can be kept continuously at work, the number of square yards rolled in a day may be more than 1,000, but, as a rule, 500 sq. yd. or 600 sq. yd. will be nearer the truth. The cost of working also varies, but may be taken roughly as being anything from 20s. to 30s. per day for wages, fuel, repairs, and interest on first cost.

In order to keep a macadam road in good repair, it should be kept as clear as possible from mud, for, if the mud be allowed to lie over the surface, moisture will penetrate into the foundations and assist in destroying them. Dust also should be removed, as, after the first shower, the dust becomes mud. Although water has such evil

results on the structure of the road, it is sometimes advisable, in very dry weather, to slightly water a macadam road, for after a long season of drought the surface of the road becomes baked and brittle, and is subjected to much injury by traffic. Late autumn and winter are the seasons when repairs are best carried out, one reason for this being that the defects in the road are more apparent in wet weather, every little depression in the road being revealed by the water which it contains. Another reason, and a more important one, is the fact that while it is fairly moist the roadway is in the most suitable condition for binding in with the new materials. As a rule, most of the work should be down before the end of December, though repairs of some sort or another will be required all the year round.

When it is found that a portion of the road requires repairing, the first question to be decided is whether new metalling will be required or not; for, in many cases, all that is necessary is to loosen the top layer of stones with the pick or by means of a "scarifier," to rake the stones to the proper contour and level, and then to finish by rolling. The "scarifier" is either a special machine, of which there are several in the market, or else, as is often the case, it is a road roller fitted with spikes attached to the rollers in such a way as to press into and loosen the top layer of metalling.

In carrying out large repairs it may be necessary in some cases to "lift" the road—that is, to loosen and turn over the top layers to a depth of 4 in. or 5 in., removing all inferior, rotten, or very large material. If thought desirable, new material can then be added, and the road completed. When the surface of the road is hard and compact, and yet is worn so thin as to make additional stone desirable, the old surface is not *lifted, but is* merely scored across with the pick at

intervals of 6 in. to 12 in., so as to loosen some of the stone and give the new materials a chance of being incorporated with it.

Where a road roller is not used, and the traffic on the road is depended upon to consolidate the new material, some means of persuading drivers to pass over the newly macadamised portions should be adopted. The usual method is to obstruct the untouched portions in such a way as to compel vehicles to pass over the newly repaired

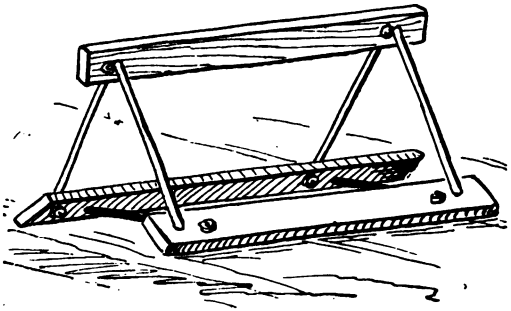


Fig 8.—Road Barrier.

portion. One form of barrier is shown in Fig. 8; a scaffold pole placed across a couple of three-legged trestles will also suffice; and portions of tree trunks are sometimes placed on the sides of repaired country roads to keep the traffic to the centre.

As a means of calculating the amount of material required in repairs, it may be useful to point out that a ton of broken macadam, when laid in a layer 1 in. thick, will cover an area of about 32 sq. yd. If, however, it has to be compressed by rolling into a layer of 1 in. thickness, then a ton of metal will cover only 24 or 25 sq. yd. From these figures it is easy to compute the weight of material that will be required, for it is obvious

that if the covering is to be 3 in. thick when rolled, a ton of metal will only cover about 8 sq. yd., or, if 4 in. thick, 6¼ sq. yd.

In some districts the use of macadam cemented by the addition of tar has been adopted with favourable results. As carried out at Nottingham, the foundation of the road is prepared much as for an ordinary macadam road, the materials being broken bricks or other ballast. Over this comes a layer 4 in. thick of tarred iron slag, which is rolled down to a thickness of 3 in. On top of this comes a layer of fine tarred slag chippings, measuring, when rolled, ¾ in. in thickness. Last of all, the surface is sprinkled with granite chippings and rolled.

At Norwich, after the foundation is prepared, a coating of tar macadam is applied, measuring 3 in. thick, and consisting of hard blue limestone or iron slag broken to 1½-in. gauge, free from dust, but containing sufficient fine chippings to fill all interstices. This is mixed in a thoroughly dry state with a sufficient quantity of stiffly boiled hot tar. After a thorough rolling with a steam roller, the surface is painted with stiffly boiled hot tar, and, after being covered with limestone or iron slag chippings and dust, it is again rolled.

At Salford the stone is broken to three gauges —namely: 2½ in., 1½ in., and ¾ in. The stone is then heated on an iron plate or floor under cover until dry and hot, and is then thoroughly mixed and incorporated with boiling pitch, tar, and creosote, until every particle of the stone is thoroughly coated. The pitch and other ingredients are mixed in the following proportions: 12 gals. of tar, ½ cwt. of pitch, and 2 gals. of creosote to each ton of stone. The prepared stone is kept under cover until required, and the metalling of the road is done in dry weather. The first layer is 4 in. thick of 2½ in. gauge; the second layer

is 2 in. thick of 1½ in. gauge; the upper layer is 1 in. thick of ¾ in. gauge. Each layer is rolled until thoroughly consolidated, and the top layer is sprinkled with sharp sand or grit.

Another method of heating the stone before applying the tar is employed in a northern watering-place where this class of road is largely used: The surface of the roadway is well rolled, after which a 2-in. coating, prepared in the following manner, is laid and well rolled. The gravel, of 2½-in. gauge, is laid in a heap about 1 ft. in thickness, and several fires are made on the top of it. These fires are covered down with refuse cinders in such a way as to confine the heat and completely evaporate all moisture from the gravel. This process is continued until the whole heap is covered with cinders and is one mass of fire. The heap is then turned over with a shovel, and gas tar is sprinkled on while the gravel is hot. After this has been laid and rolled, a layer of macadam stone of 1½-in. gauge, heated and tarred in the same manner as the gravel, is laid and well rolled. The topping or finishing layer is composed of ashes and gravel sufficiently small to pass through a ⅜-in. riddle, heated and tarred in the same manner as the other coats, and finally rolled.

CHAPTER III.

STONE PAVING.

It is now proposed to consider the various classes of pavement which are adopted when the traffic is of such a nature as to cause undue wear and tear of the surface of a macadamised road. The first cost of a macadam road is less than that of a paved road, but, with heavy traffic, the cost of maintaining the former in good repair may become so great that it is a matter of economy to undertake the greater initial expense involved in stone paving, combined, as it is, with the advantage of much smaller cost of maintenance. As a general rule it may be held that when the whole surface of a macadamised road has to be re-coated with metal every year it would be cheaper to adopt a stone pavement.

The kind of pavement to be adopted will be determined to a great extent by the amount and nature of the traffic. The accessibility of suitable paving material, local atmospheric conditions, and other considerations, also influence the choice. The gradients of the streets will decide in some measure the material to be used; stone setts may be employed on inclines as steep as 1 in 16, while wood—according to Mr. Boulnois—is not safe at a greater inclination than 1 in 36, although some authorities would allow its use on steeper gradients.

The best guide in the choice of a suitable material for any particular locality is an accurate record of the cost and length of life of previous pavements laid down in the same locality, more

especially if this is coupled with details of the amount of traffic passing over the streets. Unfortunately, in most cases, this is just the information that is not available. Mr. G. F. Deacon, in an able paper read before the Institution of Civil Engineers, named the three following items as being necessary facts to be ascertained, namely, (1) the tonnage passing over the carriageway in twelve months; (2) the width of the carriageway; and (3) the number of wheels on which the twelve months' traffic is borne. From these data the amount of traffic per yard of width and the average weight per wheel of traffic can be ascertained, thus providing a fair knowledge of the average nature of the traffic.

With regard to the wear of the pavements, Mr. Deacon recommends that one or two rows of setts extending over the full width of the street should be taken, accurately weighed, and replaced exactly level with the surface of the surrounding setts. At the end of twelve months, or any other period, the setts may be taken up again, re-weighed, and the amount of wear deduced from the loss of weight. This and other means have since been adopted in one or two localities, and the results are instructive. In Tooley Street, London, it was found that Guernsey granite setts upon a concrete foundation had worn down about 1 in. in ten years under a traffic of 316,084 tons per yard width per annum. On London Bridge, with a traffic of 15,000 vehicles in twelve hours, the setts of Aberdeen granite wore out at the rate of ·22 in. per annum.

At points where important streets cross one another there is greatly increased wear of the pavement, and special care has to be taken in the choice of a suitable material. There are also various local conditions of traffic to be attended to, such as hold good in the engineering districts of the north of England, where it is not unusual to

have loads of 40, 50, or even 60 tons carried on four wheels. Such loads are very trying to the stability of a street pavement, the foundations being more affected, perhaps, than the setts themselves. Sir Robert Rawlinson contends, however, that a light quick traffic is more destructive than is a heavy slow traffic; for a wheel, after it gets up to a speed of five or six miles an hour, no longer rolls, but progresses by a series of jumps, beating on the stones with destructive effect.

The stones used for street pavements may be roughly classed in two divisions—granites and grit-stones. Granites and syenites—these are much alike—are very hard and durable, and are almost universally adopted for pavements where the traffic is very heavy. Their disadvantages are that they wear to a smooth polish, and thus get very slippery, and that they form a noisy pavement. The latter reason has led to them being replaced in some important thoroughfares by wood, which is comparatively noiseless, but much more costly, especially in maintenance. It is probable, however, that in the near future efforts will be made to obviate the noise of traffic by improving the tyres of the vehicles, rather than by doing away with the stone pavement.

Amongst the many classes of granites used for street pavements may be named the following:—Aberdeen, Tyar Baggar (also from near Aberdeen), Guernsey, Penmaenmawr, Clee Hill, Port Nant, Port Madoc, Dalbeattie and Irish granites from Newry and Bessbrook. In addition to these, there are the syenites from the Markfield, Groby, and Mount Sorrel quarries in Leicestershire, Fogginton in Devonshire, and some Cornish stones. The two last-named are, however, too soft for heavy traffic. The Carnarvonshire syenites are dense and heavy, and form one of the very best paving materials. The old blue Penmaenmawr and

the Mount Sorrel stones are said to wear very slippery, and the latter has the objectionable quality of being very brittle under the dressing hammer. Aberdeen granite has been largely used in London, and that from Guernsey is held equally in favour by some authorities.

As to the comparative merits of Welsh and Aberdeen setts, there seems to be much conflict of opinion. The Welsh syenites are said to be inferior in hardness and durability to the Aberdeen granite, but are very largely used in Liverpool, Manchester, and the large manufacturing towns of Lancashire, no doubt because the smaller traffic upon them makes them the cheaper material for that part of the country. A comparison of the relative durability of Guernsey and Aberdeen setts was afforded when Blackfriars Bridge was repaired in 1840. The paving had then been laid for thirteen years, and it was found that the Guernsey stones were only worn down ¼in., while the Aberdeen stones were worn 1½ in.

The slipperiness of various forms of paving in London streets, and the number of accidents resulting therefrom, were made the subject of inquiry a few years ago. Observations were taken over fifty days for twelve hours each day. In one day of twelve hours 12,366 horses and vehicles passed along Cheapside, and 5,350 along Cannon Street. During the fifty days 542 accidents took place on wood pavement, 719 on granite, and 1,066 on asphalt. From these figures, and the lengths of the various kinds of pavement under observation, it has been estimated that a horse can travel 330 miles on wood pavement during fifty days without meeting with an accident, 191 miles on granite, and 132 miles on asphalt.

If the convenience of the traffic were the only thing to be considered, the cross-section would be a level line, as any cross-fall produces friction;

additional traction, and wear and tear of horse and vehicle. But a cross-fall is necessary in order to provide for the rapid discharge of rain water. The amount to be provided depends upon the water-tightness of the road surface, and varies from 1 in 30 to 1 in 40. Granite requires a less amount of cross-fall than grit stones, because of its greater imperviousness; asphalt requires less than wood. Indeed, a covering of asphalt may be considered to be absolutely waterproof. Another important consideration is the amount of longitudinal fall in the road, for, as already pointed out, a good gradient is very effective in helping to get rid of water, and a street which is level will require more cross-fall than one which has a good longitudinal fall.

Distinct from the macadamised road and the fully paved road, there is a transitionary mode of construction in which only a paved track is provided for vehicular traffic, namely, by laying down long stones in the middle of the road. Roads of this description possess some undoubted advantages, amongst which are the greatly lessened friction for the wheels of vehicles and the retention of a rough track for the horses' feet. One constructed some forty or fifty years ago in the Commercial Road, London, for the use of one of the dock companies, was formed of blocks of granite 16 in. wide and 12 in. thick. They were laid in lengths of 5 ft. or 6 ft., the space between them being filled in with stone paving. It was found, however, that the wear was very irregular, and ruts were worn on the surface of the granite.

As a general rule, two lines of granite blocks are laid longitudinally about 2 ft. to 2 ft. 4 in. apart, and the space between them is filled in with boulder paving. The blocks themselves are 2 ft. wide by 8 in. deep and 5 ft. in length, and they rest on foundations of rammed gravel on which is

placed a layer of sand; upon this sand the stones are bedded.

The importance of a good foundation, and the general principles involved in its construction, were dealt with in Chapter I. As was there pointed out, solidity of construction is of first importance. The foundation, when once constructed, should be everlasting, the wear being confined entirely to the surface formation. When it is proposed to lay down a new pavement on the site of an old road or street, advantage may be taken of the solid state of the ground to lay the new pavement directly on the surface of the macadam or old pavement, care being taken, of course, to rectify any irregularities of surface before doing so. This is a method which was formerly much used, but the introduction of the mechanical stone-breaker has given an increased value to the old paving setts, and, however badly they might be worn, in all likelihood they would now be worth taking up for breaking into macadam in the machine.

A common form of foundation consists of a layer of broken stone, ballast, or cinders, 12 in. or 15 in. thick. The materials vary according to locality; in the north of England, where ironworks abound, slag affords an excellent material; in some parts gravel is largely used; while in other parts broken bottles, ashes, old pots and pans, and other refuse are tolerated.

A much better type is the pinned foundation introduced by Telford and described in Chapter I. It consists of flat stones placed close together on their edges and wedged up tight. The projecting pieces are then knocked off, and the interstices filled in with small stuff and rolled. Sometimes the traffic is allowed to pass over this rough formation before the pavement is laid, in order to assist in consolidating the foundation. The setts

are usually bedded on a thin layer of sand or cinders placed over the foundation.

The best foundation known is formed of concrete. This is rather expensive, costing quite twice as much as a Telford foundation; but it is becoming recognised that in road-work the most expensive construction is, in many cases, the cheapest when maintenance over a long period of years is taken into account. Mr. G. F. Deacon, at one time city engineer of Liverpool, was one of the first to make use of it extensively, and the following is an abridgment of his description of the method to be adopted. The ground on which the foundation has to be laid is well watered; and upon it is scattered a layer of wet broken stone like coarse macadam. Upon this is spread a thin layer of Portland cement mortar, with broken stones on top of it. The whole mass is then well beaten with beaters something like large spades (see Fig. 9). These are made of sheet iron about 12 in. square and ¼ in. thick, with straight handles about 4 ft. 6 in. long. After this beating of the mass, another layer of mortar and another of stone are followed by more beating, and so on until the required thickness is attained, when the surface is finished by rubbing with the beaters to the proper curvature of the roadway. The usual thickness of this foundation is 6 in. Before laying the paving setts on this foundation, it should be left untouched for as long a period as circumstances will allow—certainly not less than eight days, and preferably three or four weeks. The concrete as at present used in Liverpool is composed of broken stone 8 parts, gravel 6 parts, and Portland cement 1 part, all measured dry and separately. When mixed together the proportion becomes 1 of cement to 11 of broken stone and gravel mixed, as 3 parts of the gravel make their way into the interstices of the broken stone.

A foundation of the above description, besides being rigid and capable of bearing the heaviest traffic, has the merit of presenting a smooth, even surface for the paviors to lay the setts on, and, being homogeneous, is not liable to give way in spots while remaining good elsewhere. Perhaps the only objection that has been raised against it, apart from the question of cost, is that the strength of a concrete foundation when laid in a cambered or arched form will sometimes keep up the road even when the substratum of earth has fallen away from any cause, and that there is a probability of gas from the mains getting into the cavity and blowing up the roadway and the traffic upon it; but this is a very remote contingency.

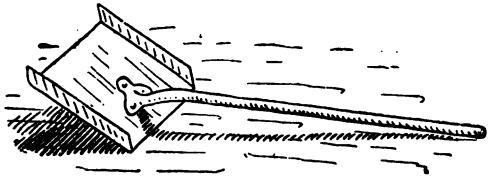


Fig. 9.—Iron Beater for Concrete Foundations.

In some cases the foundation is made of bituminous concrete, which is practically the same as tar macadam. Stones broken as for macadam are laid to almost the required thickness of the foundation, and are then grouted with a hot mixture of pitch and creosote oil. This sinks to the bottom, and eventually fills up all the interstices. Stone broken to a smaller gauge is laid on the top while the asphalt is still warm, and is well rolled in. A foundation formed in this way sets quite hard in a few hours, and is impervious to water, thus affording an excellent protection to earths which are easily affected by moisture.

In nearly all the cities and towns where concrete foundations are in use, a uniform thickness of 6 in.

is adopted. At Belfast and Huddersfield the thickness sometimes becomes 9 in., while at Ipswich a thickness of 3 in. only is used. The proportions of the ingredients vary from 1 of cement to 4½ of stone and gravel or sand, to 1 of cement to 7 of the other materials. Blackburn, Belfast, Newcastle and Preston still use the Telford or hand-packed foundation in some of the streets. Manchester and Salford adopt a 12-in. foundation of ballast or cinders and gravel.

The old-fashioned cobble-stone or boulder paving, still to be met with in small country towns, has many defects. It is very unpleasant to travel over, and it is, at the same time, very noisy; moreover, as the rounded boulders cannot be packed close together owing to their shape, great spaces are left, in which horse droppings and filth accumulate. Water stands readily in the hollows, and to get rid of it a large amount of cross fall has to be given. The only advantage in such a system of paving lies in its great durability. It may also be pointed out that for garden paths it has a pleasing appearance, especially when arranged in patterns formed with stones of different colours.

When used for street paving, the boulders are set upon a layer of sand 3 in. or 4 in. thick, under which has been laid a good foundation, preferably a hand-pitched or "pinned" foundation. As a limit to the size of the stones, it is usual to specify that not fewer than forty nor more than fifty stones shall be laid to the square yard. In some cases the stones are graduated in size from the smallest in the centre of the road to the largest on each side.

With regard to granite sett pavements, there is considerable diversity of opinion as to the proper size and shape of the setts to be used in stone paving. Formerly large stones were in favour, but

the tendency in later years has been to adopt smaller sizes, particularly as regards the width of the sett; the width is the dimension measured in the line of traffic.

In 1843 the celebrated "Euston pavement" of Mount Sorrel granite was laid at Euston Station. The setts were 9 in. deep and 3 in. wide, and the excellent results obtained led to the extensive use of this width. A very general dimension now is 4 in. for the width. This enables a horse to get a good hold of the road even on steep inclines.

The depth of the sett is controlled to some extent by the durability of the stone and the nature of the traffic, and is usually from 4 in. to 6 in. With a deeper stone there is, of course, a possibility of longer wear, but there is increased first cost. With a very deep sett the pressure of the horses' feet tends to push the stones over or cant them backwards; indeed, it has been said that, looking across the width of a street paved with such setts, the joints, instead of forming a straight line from curb to curb, present a sinuous or waving line, being pushed in opposite directions at each side of the street by the direction of the prevailing traffic.

The length of the sett is governed chiefly by considerations of weight. The sides and ends should be dressed quite square with the top and bottom, so that the latter are both of the same size. This is necessary in order to allow of the setts being reversed when badly worn; it also secures the stability of the sett on its foundation.

When laying them in position, take care to "break joint," so as to avoid having the joints directly opposite each other in the line of traffic. If this be neglected, the wheels of vehicles will naturally travel in the slight depressions caused by these joints and tend to wear grooves or ruts in the neighbouring setts.

As examples of various sizes of setts in use, it may be stated that at Leeds the granite setts are 6 in. deep and 3 in. wide by 7 in. or 8 in. long. At Birmingham they are 6 in. deep and 3 in. wide. At Liverpool they are in some streets 6¼ in. deep by 3¼ in. wide and 5 in. to 7 in. long, and in other streets they are 5 in. deep by 3 in. wide.

Each sett must be firmly supported over its whole area, and, as the bottom of a sett is comparatively rough and unequal, it would not suffice if it were laid directly on a hard concrete foundation or a rough stone filling of a hand-pitched foundation; a layer of some finer material has to be interposed. In some cases fine sand is used to a thickness of ½ in.; in others, fine gravel. Sometimes, usually where the foundation is composed of hard ballast, a 3-in. layer of cinders forms the cushion bed for the setts. At Hull and other towns 4 in. of clean, dry ashes are specified.

The setts must be placed close together, so as to leave the joints as fine as possible. If the joints are too fine there will not be sufficient hold for the horses' feet, but if the joints are made wide, the edges of the setts are soon broken away and the tops of the setts become rounded and slippery. Contractors, unless carefully supervised, will lay the joints too wide, as it is to their interest to make a given weight of setts cover as large a superficial area as possible.

After the setts are laid and well rammed down with a punner, various methods are adopted of filling in the joints. In most cases fine granite or limestone chippings—called "racking"—are sprinkled over the surface and brushed into the joints. Gravel and slag are also used for this purpose. The racking, of whatever material it may be composed, is rammed down tightly into the joints, and, in some classes of work, the jointing is then complete.

When it is desired to make a pavement that shall be impervious to water—a distinct advantage as regards the preservation of the foundation—further measures are taken. A common practice is to fill in the joints with a grouting of Portland cement and sand, or lime and sand. This fills in all the empty spaces between the setts and the racking, and, when solidified, binds the whole pavement into one compact mass.

A method of jointing much in favour in Liverpool, Manchester, and other northern towns, is to fill in the joints with a mixture of pitch and creosote oil, generally called "asphalt," but, of course, having little real affinity to the true asphalt or bitumen. Pitch boilers on wheels are kept on the site of the work, and the pitch boiled when required. To determine the quality of the heated pitch, small portions are drawn off, cooled in water, and tested by kneading in the fingers. If too brittle and hard, it is softened by adding more creosote oil in the boiler. The quality of the pitch—which is obtained from coal-tar—may be judged in a rough-and-ready fashion by chewing a piece before it is boiled: if it can be chewed easily it is good; if it crushes and crumbles between the teeth it is too hard and requires the addition of more creosote. From 50 to 60 gallons of creosote are required to each ton of pitch.

The heated pitch is drawn off into buckets and carried to the spot where it is required. It is then poured into the joints either from long-handled ladles or from cans provided with a long spout. The filling-in of the joints is continued until the pitch rises to the surface, and the operation is completed by sprinkling the surface of the pavement with fine gravel. When this bituminous grouting sets hard, it forms an admirable jointing material, quite impervious to water, and increases the life of [illegible]dations.

The one defect of the pitch filling is that in hot weather it sometimes becomes so soft as to run down from the crown of the road into the channels, forming a very unpleasant footing for wayfarers who may wish to cross the road. This tendency to melt can be partially remedied by the addition of sand to the pitch during boiling. In some towns the defect is obviated by using the bituminous mixture to fill in the joint only up to 1 in. from the upper surface of the setts, and then, when the pitch is set, filling in the remainder of the joint with a grouting of 1 part of cement to 2 parts of sand.

With regard to the amount of stone required to pave a given area, a ton of Welsh granite setts, such as are used in Lancashire towns, will cover a space of 3½ sq. yd. when the setts are 6 in. deep. The trap rock setts obtained from the quarries of Wicklow and used for paving the streets of Dublin are reported to cover from 3 to 3½ sq. yd., 6½ in. deep. Naturally the specific gravity of the stone affects the covering power, a light stone covering a larger area than a heavy one, and this is a consideration which has to be taken into account in comparing the relative costs of different paving materials. The table on p. 41, from Mr. Boulnois' "Municipal and Sanitary Engineer's Handbook," shows the number of square yards covered by one ton of granite setts of different sizes.

The covering power will, of course, vary with the specific gravity of the granite used.

Grit stone paving is common in the North of England, though but little known in the southern counties. It is formed of setts made from the millstone grit formations. These are sedimentary rocks and laminated in structure—that is to say, they are formed of layers of material and will split in certain directions more readily than they will in others. The millstone grits are geologically associ-

	Depth, inches.		*Width, inches.*		*Length, inches.*			*Square yards.*
Setts	5	×	3	×	5 to 7	1 ton will pave		4·5
,,	6¼	×	3¼	×	,,	,,	,,	3·6
,,	7¼	×	3¼	×	,,	,,	,,	3·1
Cubes	3¼	×	3¼	×	3¼	,,	,,	6·7
,,	3¾	×	3¾	×	3¾	,,	,,	5·8
,,	4	×	4	×	4	,,	,,	5·4
Blocks	4	×	4	×	6	,,	,,	3·6
,,	4	×	3	×	3	,,	,,	5·4
,,	5	×	3	×	3	,,	,,	4·4
,,	6	×	3	×	3	,,	,,	3·7
,,	6¼	×	3¼	×	3¼	,,	,,	3·25

ated with the Coal Measures, and are, in consequence, mostly found in Lancashire and Yorkshire. They are much softer than the granites and whinstones, and the best of them lasts only half as long as a good granite pavement; but they are not so slippery, and provide a safe foothold on gradients which would be too steep for granite and altogether out of the question for wood or asphalt. They are, besides, not so noisy as granite. Their cheapness in first cost leads to their extensive use in streets where the traffic is not very heavy. There are quarries for these grit stones at Bradford, Bingley, and Bolton Wood in Yorkshire, while in Lancashire the most noted quarries are at Stacksteads, Rawtenstall, and Rakehead.

As to the sizes of the setts, the same considerations as for granite pavements have to be borne in mind, except that the rougher surface of the grit stones makes it possible to use setts of a greater width than with granite. A horse has not the same tendency to slip over the sett as it has on granite. With a grit pavement the stone itself is sufficiently rough to give foothold, and, in consequence, the width of the sett is made from 5 in. to 7 in. or 8 in. Its depth is seldom less than 6 in., and sometimes 8 in. or more. At Leeds some

streets are paved with setts of 8½ in. depth; in other parts of the town 6 in. is the depth used. At Bolton 8-in. setts are used. At Blackburn, Manchester, and Salford they are 6 in. in depth.

In squaring grit stones at the quarries, the grain or laminations of the stone must be arranged to run along the length of the sett, and vertically. Thus the feet of horses and the wheels of vehicles bear on the edges of the thin leaves or laminations, which, although in some cases quite imperceptible to the eye, form the material of the sett. This arrangement of the grain of the stone is shown diagramatically in Fig. 10; it will be seen that the area of cleavage between two layers of stone is equal to 7 in. by 6 in., or 42 sq. in. If the sett were cut as shown in Fig. 11, it would split across from front to back, and there would be a smaller area of cleavage to separate than in Fig. 10. In this second case it would equal 6 in. by 5 in. or 30 sq. in. Supposing the stone were cut as shown in Fig. 12, although the actual cleavage area would be 35 sq. in., it is obvious that the top layers of the stone would shell off very quickly under the hammering of traffic, as they do not receive support from the adjoining setts.

With respect to the foundations, what was said in the case of granite paving applies here also. Grit setts are sometimes laid on a concrete foundation, but they are usually placed on the broken stone and cinder foundations previously described, and the joints run in with the bituminous material already mentioned. As the millstone grits are not as heavy as granite, it follows that a given weight of material will cover a larger area than would granite setts of the same depth. For setts of 6 in. depth, 1 ton will usually cover about 4 sq. yd.

At points where streets intersect, or where one street runs into another, the street pavement should be made to suit the traffic as far as possible.

If the setts are laid lengthwise across the line of one street in the usual manner, the foothold for the horses travelling in that street will be at its best, but it will be at its worst for the traffic at right angles. A method of overcoming this difficulty is to use square setts of a small size, such as 3 in. or 4 in. square, so as to make the number of joints equal either across or along that particular part of the pavement. Sometimes the difficulty is met by running the courses of setts diagonally into the line of the street intersected.

For the use of foot-passengers crossing the street, it is usual to lay special crossing setts or

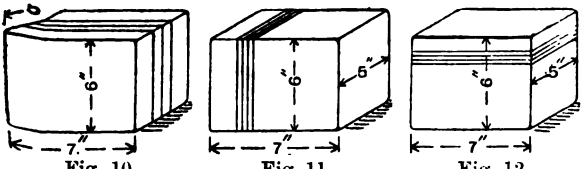


Fig. 10. Fig. 11. Fig. 12.

Figs. 10 to 12.—Diagrams showing Correct Methods of Squaring Setts.

blocks in continuation of the footpaths. The crossing stones should be chisel-dressed on the top, and carefully squared on the edges and joints. They should be kept a little higher than the adjoining setts, as they then keep cleaner than the surrounding pavement.

Where narrow streets or crossings from courtyards intersect the footpath, it is the custom in some towns to make no sudden drop from the kerb of the footpath, but to lay two or three courses of setts parallel to and gradually inclined up to the kerb, so as to make the crossing hollow in the centre. This is a decided advantage to persons using the footpath.

A kerb at the edge of a footpath serves as a

guard to keep the vehicular traffic from encroaching. As the surface of the footpath is generally made sloping, the kerb also acts as a buttress to keep the flagstones, asphalt, or other material in

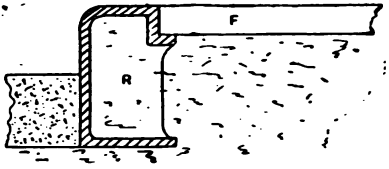


Fig. 13.—Cast-iron Kerb.

position, and, in the same way, they take whatever thrust may arise from the arched formation of the roadway. In order to ensure the necessary stability of the kerbs, they should be set deeply in the foundations. The convenience of foot passengers requires that the height of the kerb above the street pavement shall not be too great, while

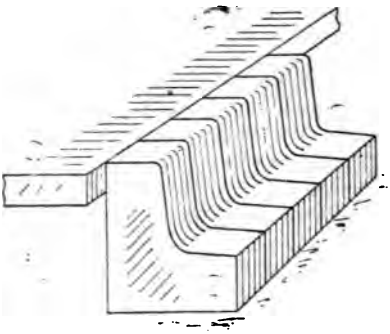


Fig. 14.—Blue Brick Kerb.

the efficiency of the kerb as a protection against the inroads of vehicles depends on its not being made too low. The model bye-laws of the Local Government Board recommend that the height of

the kerb above the channel of the carriage-way shall be "not less than 3 in. at the highest part of such channel, and not more than 7 in. at the lowest part of such channel."

A great deal of wear comes upon the kerb from the scrubbing of wheels, especially at the corners of streets, and in busy thoroughfares they are liable to become badly worn. This, in some cases, has led to the use of iron kerbs, which, however, wear very slippery. Fig. 13 shows a section of a cast-iron kerb B, provided with a rebate to receive the edge of the flag-stone F, and strengthened

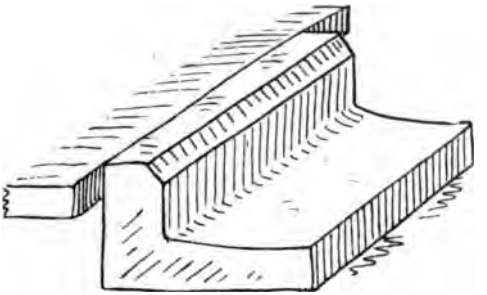


Fig. 15.—Combined Kerb and Channel in Blue Brick.

internally by ribs cast in the same piece as the body of the kerb; wrought-iron kerbs of similar design are said to have been used.

In cases where the traffic is not excessive, a very neat kerb is formed by the use of specially shaped blocks of blue bricks. One pattern, made at Ruabon, is shown by Fig. 14. Another pattern, made by a Staffordshire firm, and which combines, along with the kerb, a dished channel, is shown by Fig. 15. Fig. 16 illustrates a simpler form of kerb which is to be had in blue brick, and is suitable for footpaths where the traffic is very light. Another useful material is blast-furnace slag which

can be manufactured into bricks and paving blocks. At Norwich, kerbs are formed by the use of slag bricks, measuring 12 in. by 12 in. by 3½ in., set on edge. Cement concrete also lends itself to the

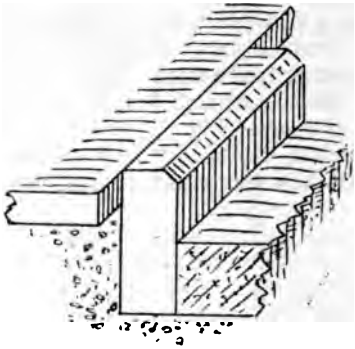


Fig. 16.—Another Blue Brick Kerb.

purpose. Two forms of concrete kerb, designed to form conduits for telegraph, telephone, or electric-lighting wires, or gas or water pipes, are shown in

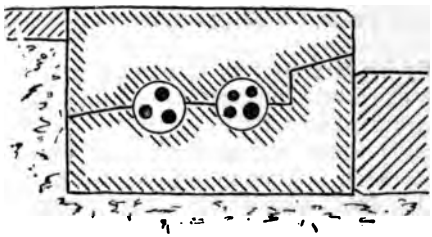


Fig. 17.—Concrete Kerb to contain Pipes and Wire.

Figs. 17 and 18; with these the wires or pipes are accessible without having to pull up the street paving. In Fig. 18 the upper portion overhangs the box in order to throw off rain, and the small

pipe shown at the bottom leads away any moisture from inside.

To carry away the water falling upon the surface of the street, gutters or channels are provided

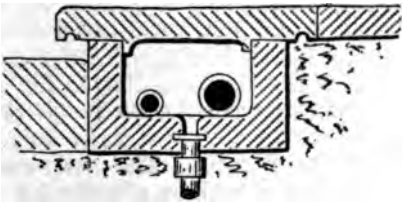


Fig. 18.—Concrete Kerb to contain Pipes and Wire.

at each side, against the kerbstones. The contour of the street section causes the water to fall towards these gutters, and, at regular intervals, gullies, with cast-iron cover grids, lead the water down to the sewers. The usual manner of forming the channels in paved streets is to lay two or three courses of setts in the same fashion as in the ordinary paving, but with their longest dimension parallel to the kerb. By this means the water

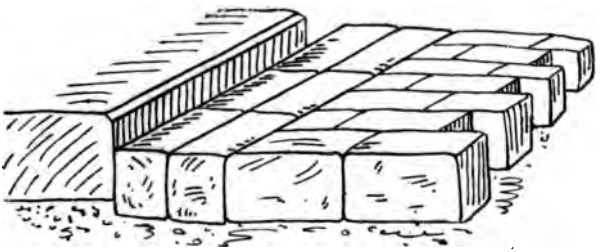


Fig. 19.—Setts Laid to form Channel.

flowing down the channel has to pass over fewer joints, and meets with less obstruction than it would if the ordinary paving were carried right up to the kerb; this arrangement is shown in Fig. 19.

To lessen still further the number of joints, special channel stones are used in the best class of work, bedded on the same foundation as the setts. These, at Glasgow, are 12 in. to 14 in. broad, 6 in. to 7 in. deep, and 3 ft. in length. At Salford, they are 12 in. broad, 5 in. deep, and not less than 2 ft. in length. Channels of this description should be 12 in. to 18 in. wide, according to the amount of water they may be called upon to take, and the inclination at which they are laid; this should not be flatter than 1 in 200. The whole surface of the channel stone should be slightly lower than the surface of the adjoining paving setts. If a slight fall is given towards the street also, it will tend to keep the wheels of vehicles from grinding against the kerb. Channeling is constructed of other materials besides stone. At Norwich, for example, slag blocks, 12 in. square and 3½ in. thick, bedded on cement concrete, are used.

CHAPTER IV.

WOOD PAVING.

THE chief advantage to be gained by the use of wood paving lies in its comparative noiselessness, but it also has a pleasant appearance, being very smooth and even, and at the same time this smoothness makes it one of the easiest pavements for traction. Indeed, wood offers less resistance to traction than any other class of paving, with the exception of asphalt. Further advantages are that a wood pavement produces very little dirt and is easily kept clean.

The disadvantages of wood paving are many, the first being the unsuitability of wood as a paving material from the sanitarian's point of view. Owing to its porous nature, it absorbs readily the moisture which falls upon its surface, and so becomes saturated with the noxious liquids and filth common to every road. To make them last as long as possible, the blocks are set with the grain of the wood vertical, and this intensifies the propensity to absorb moisture. In dry and hot weather disagreeable odours are given off by the saturated wood, and, worse than this, the dust which is produced by the wearing of the blocks carries the germs of disease and noxious products into the nostrils and lungs of passers-by. There is reason to think, too, that in narrow streets, fenced in by buildings so high as not to permit of the action of the sun on the surface of the pavement, the pestilential character of the absorbed filth remains still more pronounced than in the broader thoroughfares where the sun and air are

able to exercise their purifying functions. Perhaps, when the use of the harder Australian woods becomes more general, it will be found that their superior density has to a very great extent mitigated the evil.

Another objection to the use of wood paving is that when partially wet and coated with slime, it becomes dangerous to horses, and, to bring it into fit condition for traffic, requires to be coated with sand, gravel, shale, or other gritty substances. In frosty weather, too, it is very dangerous.

Wood paving is not adapted for very heavy

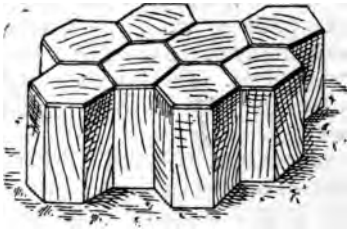


Fig. 20.—Hexagonal Wood Paving Blocks.

traffic, and its life is much shorter than that of stone pavement. Frequent renewal is necessary. Its first cost, also, is greater than that of granite. Where tramways are laid in a street, wood is apt to be badly worn near the tramrails, on account of the difference in hardness of the two materials. To keep it in good condition it requires to be well washed once a day, and this is, of course, an expensive operation.

Blocks of wood, set with their grain vertical, have been used in Russia and Germany for many years, and in those countries, as well as in France and Belgium, wood pavements are to-day in general use. In 1812 Loudon suggested the use of cubic blocks of wood, laid in mortar on a foundation composed of flagstones or cast-iron plates;

but there seems to be no record of his suggestion having been put into practice. In 1835 several streets in New York were paved with hexagonal blocks of fir (Fig. 20), 6 in. across and 8 in. deep, and in some cases 12 in. deep, on the system invented by Mr. David Stead. In a modified form, the same system was used in England in 1839 and 1840. The foundation for these blocks, as laid in Piccadilly, Manchester, was composed of a bed of lime concrete, 3 in. in thickness. Another and inferior description of wood pavement, laid down by Mr. Stead, was composed of round blocks of wood (Fig. 21) set close together with the grain

Fig. 21.—Round Wood Paving Blocks.

vertical and the spaces between filled in with gravel or sand. In 1838 a patent was taken out in England for paving roads with tapering wood blocks, boiled in tar and dowelled together. Mr. William Freeman's system of making paving blocks with a mixture of indiarubber and sawdust was patented in 1840. A few years later, in some localities, pavements were put down the wooden blocks of which were fitted together in iron frames, which were themselves fitted together to form the pavement.

In the United States the Nicholson pavement was at one time widely used. It consisted of a foundation of boards laid flat on the ground, and a superstructure of blocks sawn to an even length of 4 in. to 6 in., and a width of 2½ in. to 3 in.

The blocks were laid across the line of the street, and secured by a thin strip of board nailed to the blocks and reaching not quite to the surface. The space above this strip was filled in with fine gravel

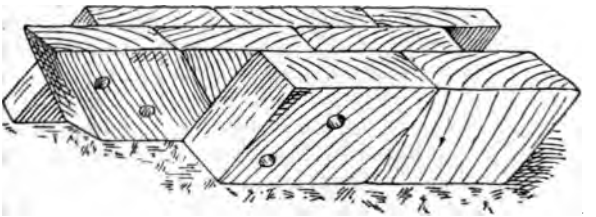


Fig. 22.—De Lisle's System of Wood Paving.

and a coating of tar spread over the whole pavement.

In 1840 the system (Fig. 22) invented by the Count de Lisle received attention in England. The blocks were pinned together by wood dowels or trenails. In a more recent system embodying the same idea, strips of wood ran between the blocks and were dowelled to them by wooden pins passing through the strips and into the blocks.

Carey's system was one that met with some favour in London, and had certain good features.

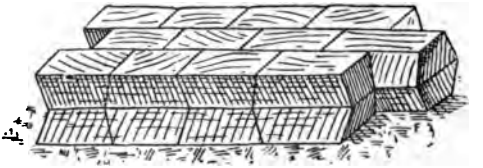


Fig. 23.—Carey's Dovetailed Wood Paving Blocks.

It consisted of blocks of wood about 12 in. long by 6 in. wide and 8 in. deep, their chief peculiarity lying in the fact that the sides and ends of each *block were in* a fashion dovetailed into the neigh-

bouring blocks in the manner shown in Fig. 23, and so helped to distribute the pressure of the traffic over the blocks.

Two other systems are shown in Figs. 24 and

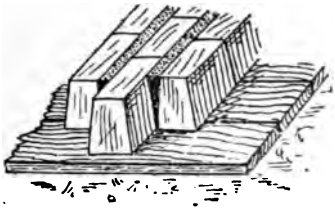


Fig. 24.—Tapered Wood Paving Blocks with Wide Joints.

25. In the first of these, the blocks were of tapered section, laid on a plank foundation, and the spaces between the blocks filled in with bituminous cement, the object of this arrangement being to provide good foothold for the horses. In the system shown in Fig. 25, blocks of rectangular section were used, with holes bored partly through the blocks from each side, so as to receive the cementing material run in between the blocks, and thus serve to bind each block to those next to it.

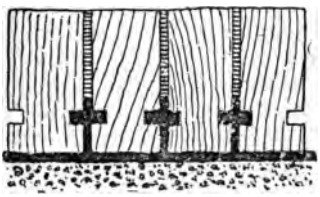


Fig. 25.—Wood Paving Blocks with Auger Holes for Cement.

From this period to the present time the tendency of all improvement has been in the direction of simplicity. About 1875, Henson's system came into vogue, in which simple blocks of deal 6 in.

in depth were laid side by side, with strips of roofing felt interposed to allow of the swelling of the wood when wet, for it had been found that the expansion of the wood pavement when saturated with water was sufficient to displace the kerbstones on either side of the road, to break off iron lamp-posts, and do other damage.

The porous nature of wood paving allows water to penetrate through to the foundations much more readily than through a stone pavement, and in the early days of wood paving it was found that the ballasting or earth upon which the blocks were laid used to work up through the joints in the form of mud, until the foundation became gradually destroyed, and the pavement fell into bad condition. A partial remedy for this defect was found in the formation of a platform of planks on which the blocks were laid. The ballasting was kept down by this, and the evenness of the paving was also maintained.

A much better remedy, however, was the formation of a foundation in a material—concrete—which was not affected by water, especially when this was accompanied by the filling in of the joints between the paving blocks with some substance which would keep out water as much as possible. At the present time almost all wood pavements are laid on a concrete foundation, varying in thickness from 3 in. up to as much as 12 in., according to the nature of the subsoil. In some cases the concrete is made with Portland cement; in others lime is used. At Ipswich a 3-in. foundation of Portland cement concrete is used, the concrete being composed of 1 part of cement to 5 parts of shingle and 1 part of sand.

The thickness adopted in most towns is 6 in. A thickness of 8 in. is used at Nottingham, and 9 in. at St. George's-in-the-East, London. Lime concrete 6 in. in thickness, with a facing of cement

2 in. thick, is used at Bath. Lime concrete is also used at Bradford.

Sometimes a layer of sand or fine gravel is interposed between the blocks and the concrete foundation for the purpose of bedding the blocks upon, and besides answering this purpose it is found, where the joints are run in with pitch or asphalt, that it assists in keeping the blocks from rising from the foundations. The bituminous mixture penetrates the sand underneath the blocks, and adheres to the under surface of them, cementing them down to the concrete. Otherwise, there is sometimes a tendency for the whole pavement to rise from the foundation through the swelling of the wood from moisture. A layer of sand ½ in. or 1 in. thick is used in this way at Carlisle, Derby, and other places.

In the early history of wood-paving, blocks 8 in. or 9 in. across, in the shape of hexagons, were used, or rectangular blocks as large as 12 in. by 6 in. These large blocks made a cheaper pavement, inasmuch as the labour on a certain area of pavement, both in the forming of the blocks and the laying of them, was less than it would be with blocks of a smaller size; but they had the attendant disadvantage that when a block wore out sooner than its neighbours, from any inferiority of the material, it created a large and unsightly depression in the roadway. The sizes of blocks used have gradually diminished until at the present time the general size may be taken as 9 in. long by 3 in. wide, with a depth which varies from 6 in. to 4 in. or less. The lesser depths are only used with the hard Australian woods, which have been introduced much more considerably of late years. Deal and other soft wood blocks are about 6 in. deep; in Birmingham, for example, the blocks are 8 in. by 3 in., and 6 in. deep, and in Paddington they are 9 in. by 3 in., and 6 in. deep.

To preserve the blocks as far as possible from the rotting effects of alternate dampness and dryness, they should be, especially in the case of the softer woods, creosoted thoroughly by the impregnation of their fibres under pressure. Unless this process is done thoroughly, it is of little use. Occasionally the blocks are dipped in some preservative solution, or in tar, but any such outside coating is quickly worn away under traffic. To be effective, the creosoting should be carried out under a pressure that will ensure 10 lb. or 12 lb. of creosote oil being absorbed by each cubic foot of wood; and a block when cut open should show the presence of the creosote oil through all the interior. Mr. Boulnois says that the creosote used should be specified to be heavy oil-tar, free from all ammoniacal water, and containing not less than 5 per cent. of tar acids. It may be pointed out that creosoting, when applied to paving blocks, is by some described as being worse than the evil it is intended to remedy, on account of the smell to which it gives rise.

In the early days of wood-paving, provision was usually made at the joints for a better foothold than was afforded by the substance of the wood-block itself. The blocks were laid at greater distances apart than those now adopted, and the joints were filled in with gravel, sand, or other materials which were not so slippery as the wood. Joints as wide as 1¼ in. are specified in some of the earlier systems. The tendency has been gradually to reduce the space between the blocks, until now they are laid either with joints ½ in. in width, or with close joints—that is to say, with the blocks in contact. As showing the importance that was formerly attached to wide jointing, a system is illustrated by Fig. 24, p. 53, in which the blocks taper upwards so as to provide a good width of joint. In order to get joints of a regular

width, thin strips of wood are placed between the rows of blocks as they are laid, and are removed before the "racking' and grouting are applied. Sometimes, instead of these strips of wood being used, each block has three iron studs driven into one side, the thickness of the heads of the studs keeping the block at the proper distance from its neighbouring block. These studs, becoming embedded in the material used for grouting the joints, help to keep the blocks from rising from the base.

Another method of effecting this is by boring holes in each side of the blocks, as shown in Fig. 25, p. 53; the cementing material runs into the holes and forms a key, binding the blocks into one mass.

As to the choice of material to be used for running in the joints, after the "racking" of gravel or other material has been filled in, opinions are divided between a grouting of lime or one of Portland cement and pitch or bituminous cement—such as was described when discussing tar macadam (p. 26). Most of the London districts adopt a grouting of Portland cement, while in the North of England the pitch jointing is more in favour. Sometimes a combination of the two materials is used by filling in with asphalt or pitch to a height of $\frac{3}{4}$ in. or 1 in. above the bottom of the block, and then grouting the rest of the joint with Portland cement. Latterly, however, as stated above, close joints are being adopted, and when this is the case all that is necessary is to spread hot tar over the surface of the pavement and brush it over the blocks until it disappears in the joints. The pavement is afterwards sprinkled with a coating of gravel to give the necessary roughness for traffic, though this has been objected to as damaging the lasting qualities of the pavement. It is urged that the small pebbles are

driven partly into the surface of the blocks, and then, becoming displaced, leave indentations which allow the water to penetrate into the fibres of the wood.

With respect to the relative merits of pitch and cement grouting, cement has been said to bring about dry rot in the blocks, owing, possibly, to the moisture in the cement at the time of application, and the complete exclusion of air afterwards. Pitch, on the other hand, is known to exercise a preservative effect.

To guard against the effects of expansion of a wood pavement under the influence of moisture, a common practice is to provide an "expansion joint" along each side of the street, next to the kerb. This is a space $1\frac{1}{2}$ in. or 2 in. in width left between the wood paving and the kerb, and afterwards filled in with clay, asphalt, or the mixture of pitch and creosote oil described on p. 26. When the blocks expand, this soft material gives way under pressure. Instead of having this softer material in a continuous strip, a better plan is to provide it at the ends of alternate courses of blocks on both sides of the street, each course of blocks having an expansion joint either on the left or on the right side of the street. This will be more clearly understood by reference to Fig. 26, where the shaded portions represent the soft material. The courses of blocks shown between these shaded portions have their expansion joints at the other side of the street.

Until the last few years, fir or red deal was, in the majority of cases, the wood used for paving-blocks. Occasionally other woods, such as beech, were substituted, and are still used; a few years ago, Baltic red timber or yellow deal was considered the best wood to use; but since then the experience gained in the use of the Australian hardwoods, Jarrah and Karri, has modified this view.

Fir timber, in the form of yellow deals from Gothenburg, red deal from Dantzic, Memel, or Riga, or as pitch pine from North America, has been in use at Bath, Birmingham, Bradford, Bolton, Bristol, Cardiff, Huddersfield, Hull, Ipswich, Lincoln, Liverpool, Norwich, Nottingham, Salford, and in the bulk of the London districts, including Greenwich, Hammersmith, Holborn, Lambeth, and Westminster. This class of timber is too soft to be altogether satisfactory as a paving material, both from its want of lasting properties and its insanitary drawbacks.

Beech is much harder and finer in texture than

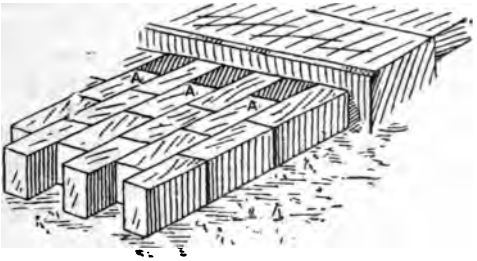


Fig. 26.—Expansion Joints in Alternate Courses of Wood Blocks.

fir, and at the same time lighter. Its growth being widely distributed over England, Scotland, Europe, America, and Australia, the timber is cheap enough to allow of its use for paving. It has been used for this purpose at Bolton, Bradford, Bristol, Bury, Carlisle, Dublin, Edinburgh, Liverpool, Manchester, Newcastle-on-Tyne, St. Pancras, and Sunderland. It is not spoken of very favourably by the authorities of Bradford, Dublin, St. Pancras, or Sunderland, but has been recommended by Bolton, Bury, Edinburgh, and Newcastle-on-tyne. Manchester also has found it preferable to fir

The timbers which have been found to give the best results in recent years come, for the most part, from Australia and belong to the large family known as the *Eucalyptus*, which embraces a great many varieties, many of them attaining to enormous size, and covering immense tracts of country. The Red Gum (*Eucalyptus rostrata*) is a dense, hard wood, with a handsome curly grain; it is suitable for piling work, sleepers, or planking for bridges. The Blue Gum (*E. globulus*) has a free, straight grain, with great strength and density; it is specially useful for heavy beams in constructional work, Stringy Bark (*E. obliqua*), Messmate (*E. fissilis*), White Gum (*E. goniocalyx*), Ironbark (*E. sideroxylon*), and the Peppermint Gum (*E. amygdalina odorata*) are all members of the same family, but do not call for consideration here, as they are in no way suitable for paving work. Two other species, the Tallow Wood (*E. microcorys*) and Red Mahogany (*E. resinifera*), have been laid for pavements in Sydney, New South Wales, and found highly satisfactory. The species best known in England are the Jarrah and Karri.

Jarrah (*E. marginata*) is found in immense forests in Western Australia, the trees reaching heights of more than a hundred feet, with stems three feet to five feet in diameter, and fifty or sixty feet from the ground to the first branch. It is described as a semi-coastal tree, that is to say, it is not found anywhere strictly beyond the influence of the sea, and yet it does not grow in near proximity to the coast line. As a rule, the best timber is found twenty or thirty miles from the sea.

From experiments described by Mr. James P. Norringeon, blocks of Jarrah, 9 in. by 4 in. by 3 in., after being kept in an office for several weeks, near a fire, showed only fine cracks, while deal blocks of the same size developed large openings

extending across the blocks, which were warped. The weight of a cubic foot of Jarrah was 51·96 lb., compared with 33 lb. for deal, the specific gravities being respectively ·832 and ·52. The maximum absorption of water by Jarrah wood is said to be 10 per cent. of its own weight, as compared with 23 per cent. in deal.

Karri, although similar in many respects to Jarrah, has some advantages over the latter. It grows to a larger size than Jarrah; an average tree, it is said, is 200 ft. high and 4 ft. in diameter at a short distance from the ground, while the height to the first branch is about 120 ft. The timber is red in colour, and has very much the appearance of Jarrah, being hard, heavy, and tough; but it is difficult to dress. It is easy to distinguish from Jarrah on account of its greater weight. Jarrah floats in water, while Karri sinks; its specific gravity being 1·0077, or just over that of water. It will be seen from the figures given above that Karri is almost twice as heavy as deal, the weight of a cubic foot being given as 62·911 lb. compared with 33 lb., the weight of a cubic foot of deal. Its absorption of water is stated to be, at its maximum, 7 per cent. of its weight, as compared with 23 per cent. in the case of deal.

Karri and Jarrah together represent the best form of pavement timber which has yet been discovered. Their superior hardness gives them lasting qualities, whilst their resistance to moisture obviates the sanitary drawbacks which have been previously described; and they are easily kept clean. It is claimed that they are not so slippery as other woods, and, eucalyptus oil being a disinfectant, the argument has been put forward that these timbers have, on this account, a good sanitary influence. Jarrah has been put down at Leicester, Manchester, Newcastle, Nottingham, Fulham, Greenwich, Hammersmith, Lambeth, White-

chapel, and elsewhere. Karri has been used at Bristol, Manchester, Newcastle, and Chelsea, and other places.

The same difficulty arises in comparing statistics relating to the wear of wood pavements as was found in connection with pavements of stone. The nature and volume of the traffic in different towns vary so much, and the atmospheric influences to which the pavement is subjcted are so different, that it is difficult to arrive at a just estimate of the value of any pavement under conditions to which it has not been actually subjected. When accurate records have been kept of the number of vehicles and their weight, the comparison is placed upon a much sounder basis, but these particulars are not often forthcoming.

Amongst the earliest recorded experiments possessing any degree of accuracy are those made by Mr. D. T. Hope in 1844. Mr. Hope had blocks cut with the fibres vertical, horizontal, and at various angles, and the whole laid down in one continuous pavement. At the end of eighteen months the wear of the several blocks was found to be as follows:

Fibre vertical, ·125 in.; fibre at 75°, ·147 in; at 60°, ·182 in.; at 45°, ·241 in.; at 30°, ·312 in.; at 15°, ·379 in.; fibre horizontal, ·480 in. Thus there was a direct increase of wear varying from $\frac{1}{8}$ in. with the fibres vertical to four times as much with the fibres horizontal.

Coming to more recent times, the wear of pitch-pine blocks laid in the King's Road, Chelsea, in 1884 was found to amount only to ·055 in., or less than $\frac{1}{16}$ in., after being in use four and a half years. Measurements taken in Cannon Street, Bishopsgate Street Without, Tower Hill, and South London streets indicated an annual wear varying from $\frac{1}{8}$ in. to $\frac{3}{4}$ in. Taking into account the number of vehicles known to pass the Mansion House,

and the widths of the roads, it was estimated that the wear due to 100 vehicles per day per foot of width was ·083 in., or $\frac{1}{12}$ in., per year.

More recent experiments made in the Euston Road, London, N.W., with an estimated traffic of 575,544 tons per year per yard width of road, have brought out the fact that the wear of blocks of deal is six times that of Australian hardwoods, laid in the same road. Jarrah and Karri have not been sufficiently long in use for much information to be available as to their durability, but in one case where Jarrah was laid in one of the metropolitan streets, the wear, after $3\frac{1}{4}$ years, was found to be $2\frac{1}{4}$ in., or $\frac{3}{4}$ in. per year.

Blocks of Karri laid alongside the Jarrah in Chelsea in 1888 were found at the end of $4\frac{1}{2}$ years to be $\frac{1}{4}$ in. higher than the Jarrah blocks. Other records of metropolitan pavements of this wood indicate a wear equal to $\frac{1}{5}$ in. per year.

CHAPTER V.

ASPHALT PAVING.

ASPHALT is, in many respects, an excellent paving material, especially for streets and large spaces in superior residential districts, where the traffic, consisting mostly of carriages and cabs, is not of a heavy nature, and where cleanliness and a good appearance are of importance. The smoothness of its surface and its freedom from joints make it easy for travelling. There is no jolting of vehicles, consequently very little noise; indeed, the greater part of the noise is contributed by the feet of the horses. Its even surface makes it pleasant in appearance, and its imperviousness to water prevents it from absorbing noxious liquids and giving off bad smells. It can be brought to a high state of cleanliness provided a good supply of water is available. In the matter of facility of repair, it is said to be rather better even than wood-paving, as the portion to be repaired can be cut out neatly and cleanly to the exact extent required.

Whilst asphalt has many good qualities, it also has some disadvantages. Thus, the smoothness which conduces to ease of traction makes asphalt unsuitable for localities where heavy loads have to be drawn, and where in consequence a good foothold for the horses is required; this slipperiness also prevents the use of asphalt on gradients such as would be possible with stone pavements. Asphalt is very slippery when slightly wet unless kept quite clean, and this necessitates a large expenditure of water. Sanding and gravelling have

also to be resorted to at times as a preventive of accidents. Another minor objection is that, when laid alongside tram lines, a place where there is apt to be great wear and tear on the pavement, asphalt wears away, or at any rate becomes compressed below the general surface very quickly.

When speaking of asphalt, the natural bituminous product is meant, and not any artificial composition (see p. 26). Rock asphalt is a limestone rock naturally impregnated with bitumen, which is found in various parts of the globe. That used in Europe is mostly obtained from the district of the Jura mountains; from Seyssel, in France, on the west bank of the river Rhone; from Limmer, near the city of Hanover; Verwohle, in Germany; Val de Travers, near Neuchatel, in Switzerland; Ancona, in Italy; and Ragusa, in Sicily. The limestone contains only a small proportion—6 to 10 per cent.—of bitumen, and is quarried like other stone, and brought to England in rough lumps without any treatment whatever. It is of a dark chocolate colour, and in cold weather it is hard and breaks easily; in warm weather the softening of the bitumen makes it more plastic, and more difficult to break up.

The bitumen which forms the distinctive ingredient of asphalt is a natural tar, apparently produced by distillation from beds of coal and shale at great depths below the surface of the earth, and afterwards forced up through the overlying strata by volcanic agency. The bitumen is found in some parts in a semi-liquid condition; thus, at Trinidad there exists a large lake of this material one and a half miles in circumference, and there is also a pitch lake at Bermudez, in Venezuela. Asphalt is also found in Cuba, Peru, Canada, and New Brunswick, as well as in Burmah, Turkey in Asia, and Albania. After an earthquake, large masses of bitumen are found

floating on the surface of the Dead Sea, and it is thought that these are derived from bituminous springs in the bed of that inland sea. Near Clermont, in France, bitumen exudes from the ground into a kind of well, known as the "Fountain of Pitch."

The system generally adopted in England for preparing a good asphalt pavement is that known as the "compressed asphalt," as distinguished from the "mastic asphalt," or Trinidad asphalt. In the preparation of compressed asphalt the lumps of rock, just as they arrive from the quarries, in pieces weighing as much as 56 lb., are crushed by machinery to pieces the size of walnuts, and then, by means of a disintegrator revolving at a very high speed, further reduced to a fine powder capable of being passed through a sieve of ten wires to the inch. When required for use, this powder is heated, generally in roasters with revolving cylinders, to a temperature, varying with the nature of the material, from 220° to 280° F. The continuous movement of the powder in the cylinder prevents the separate particles from becoming caked together, and ensures the even heating of the whole of the powder. As soon as the superfluous moisture has evaporated, the heated powder is placed in iron-sheathed vans, covered with cloths, and taken to the street where it is to be used, and where the foundation has already been prepared for its reception.

In this country and on the Continent the foundation for asphalt pavement is almost invariably composed of 6 in. of Portland cement concrete. In Trinidad, and in some American towns, the asphalt has been laid on the surface of old macadam roads. A noteworthy point is that it is unsafe to use lias lime instead of Portland cement in the composition of the concrete, as it is liable to make the asphalt "blow."

The powdered asphalt, while still hot, is distributed over the surface of the concrete foundation in an even layer of regular thickness by raking with iron rakes which are themselves sometimes heated. Afterwards, the layer of asphalt is compressed by ramming with iron punners or rammers, with round and smooth ends, which are heated to prevent the powder adhering to them. The surface is smoothed to an even curve with another iron tool, and further ramming and rolling takes place to still further compress the asphalt. This is continued until it is quite cool. The thickness of the original layer is about 3 in., and the finished thickness is generally 2 in. This is the thickness usually adopted in England, as well as in Brussels and Paris, but in Montreal a finished thickness of 2½ in. is used. It is important that the surface of the concrete foundation be thoroughly dry before the hot powdered asphalt is applied to it, otherwise the heat will convert into steam any moisture which is present, causing fissures in the asphalt, and leading to its subsequent disintegration. One advantage of the use of asphalt is that traffic may pass over it within a few hours of the completion of the surface.

When describing the sources from which asphalt is obtained, reference was made to the remarkable lake in Trinidad known as the pitch lake. It forms a circular mass of pitch, having an area of 114 acres. The depth is unknown, as the pitch rises to the surface, but from borings which have been made it is estimated that the lake contains about six million tons of asphalt; whether the supply is still kept up from underground sources is not certain. The surface of the asphalt forming the so-called lake is of a brown, earthy material with cracks or fissures several feet in width, some filled with rainwater, some with earth, covered with a scrubby vegetation. It is said that the

substance is so solid that carts and mules can be driven everywhere over the surface. The crude Trinidad lake asphalt has the following composition:—Bitumen, 39·83 per cent.; earthy matter, 33·99 per cent.; vegetable matter, 9·31 per cent.; water, 16·87 per cent. A refining process of a simple nature is carried out by heating the crude asphalt in large tanks to a temperature of about 300° F. This drives off the water, and so liquefies the bitumen that it rises to the top of the earthy

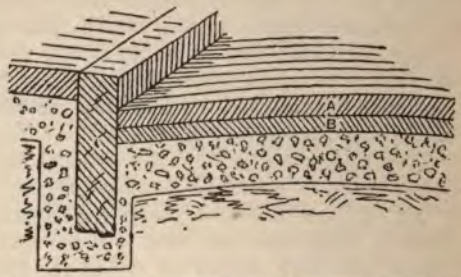


Fig. 27.—Trinidad Asphalt on Concrete Foundation.

matter, and can be skimmed off in a more concentrated form. The composition now becomes:—Bitumen, 59·86 per cent.; earthy matter, 35·82 per cent.; vegetable matter, 4·32 per cent.

In the island of Trinidad itself, the lake asphalt is used in the paving of the Port of Spain, the chief town of the island. The Town Superintendent reported in 1890 that hitherto he had used the asphalt in its crude state, pulverised by hand with cast-iron rammers, and applied cold on the already macadamised roads, on which it was either rammed by hand or rolled by steam power, and he found this method answer well without any recourse to the more complicated system in use in the United States. The streets, being almost all macadamised, only required excavating for a few

inches, and the ground below was generally firm and hard enough to receive merely a top dressing of about 2 in. or 3 in. of pulverised asphalt.

The usual practice, however, in large cities where Trinidad asphalt is laid is to construct a good foundation, generally of concrete, such as has been described in connection with compressed asphalt—that is to say, a foundation 5 in. or 6 in. in thickness of Portland cement concrete. In residential districts, where the traffic on the roads is not of a heavy description, a lighter foundation is sufficient, and in streets where there is an exist-

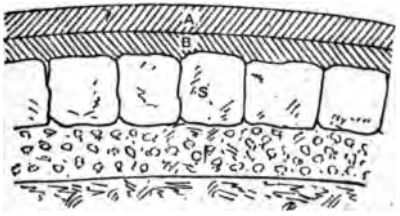


Fig. 28.—Trinidad Asphalt on Old Stone Pavement.

ing solid pavement of macadam or granite, the asphalt might with safety be laid upon this.

One of the distinguishing features of the Trinidad asphalt paving system is the adoption of what is called a binding course B (Figs. 27 to 29) between the foundation and the actual wearing surface; this is a layer of about 1½ in. in thickness of fine bituminous concrete prepared from Trinidad pitch. It serves the purpose of interlocking and binding the wearing surface to the foundation, whether the latter be of concrete, macadam, or granite setts, and it also acts in some degree as a cushion to relieve the wearing surface. The upper layer or wearing surface A (Figs. 27 to 29) is usually finished to a thickness of 2 in. In composition it consists of 12 to 15 per cent. of Trini-

dad bitumen, and 85 to 88 per cent. of mineral matter, principally sand.

Trinidad asphalt is heated to a temperature of about 300° F., the various ingredients being thoroughly incorporated by suitable machinery, and then conveyed, while still hot, to the street where the paving is to be laid, and where the foundations are already prepared. It is then spread over the surface, and regulated by iron rakes to the proper thickness and contour. Heavy rollers are afterwards used to compress and consolidate it, and it is ready for use the day after being laid. Fig. 27 illustrates the method of laying this asphalt on a concrete foundation; Figs. 28 and 29 show respectively how it is laid on a sett pavement S and a macadamised road M. The proprietors of this system of asphalt paving lay particular stress on the non-slipperiness of the pavement, which, they claim, makes it safer for traffic than other asphalts. Channels in an asphalt roadway are best formed of three or four rows of granite setts along the sides of the street, or granite slabs 12 in. to 15 in. wide.

The utmost cleanliness is requisite in maintaining an asphalt pavement in fit condition for traffic. If any dust or dirt be allowed to remain upon it, the pavement becomes at the first shower of rain extremely slippery and greasy, leading to accidents; a copious supply of water must be used for washing it down every morning before the beginning of the busiest traffic. In Berlin, not only are the main streets thoroughly washed down every morning by gangs of cleaners, but, during the day, the men and boys carry on the same work singly; and should a good shower of rain fall, they immediately assemble and make use of the opportunity of washing and cleaning the streets again.

In point of durability, asphalt as a pavement

ranks next to granite. It has been stated that in Cheapside, where the pavement had sustained for eight years a traffic of more than half a million tons per annum per yard of width, it had only been reduced in bulk five-eighteenths, and two-sevenths in weight; and if this wear was proportional throughout, it was calculated the life of the pavement in question would not be less than twenty-two years. Much would depend, however, upon the part of the roadway from which the trial piece was taken—whether from the crown of the road or near the kerbs; and again, whether new

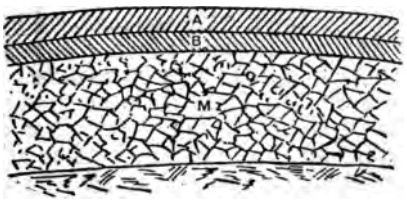


Fig. 29.—Trinidad Asphalt on Old Macadam.

asphalt had been laid for the repair of that particular spot. It is difficult to gauge exactly the life of any particular pavement of asphalt, owing to the fact that as soon as defects show themselves it is usual to repair them, and eventually it becomes difficult to judge as to which is the old pavement and which has been relaid. It is a distinguishing peculiarity of asphalt that, for some time after it is laid, it does not wear under traffic, but merely compresses, like a bed of indiarubber. It is only when its elasticity is exhausted and compression is no longer posible that the surface begins to wear away.

CHAPTER VI.

FOOTPATHS.

THE primary use of the footpath is to set apart for the exclusive use of foot-passengers a portion of the road that would otherwise be overrun by vehicular traffic. The footpath should, therefore, be elevated above the level of the road, so that it may be kept as free as possible from dirt, and not be liable to the encroachments of vehicles.

The width of a footpath is generally proportioned to the width of the roadway to which it belongs. Early Roman footpaths were half the width of the roadway, or, in other words, the two footpaths together were of the same width as the roadway. This is an ample allowance according to modern notions, and one which must have added greatly to the comfort of the foot-passengers of those days. In the specification drawn up by Telford for the fine old coaching road between Glasgow and Carlisle, which was constructed about 1820, the total width of the road is given as 34 ft., 18 ft. being macadamised for the carriage-way, and 8 ft. on each side of it being set apart for a gravelled footpath. The usual dimensions at the present day are those suggested in the Model Bye-laws issued by the Local Government Board, namely, that the width of each footpath shall be not less than one-sixth of the entire width of the street, thus reserving one-third of the entire width for footpaths, and allowing two-thirds for the carriage way.

A sloping surface to the footway is necessary to

prevent water remaining upon it; but the declination should be as slight as possible, lest it become dangerous to pedestrians when the path is coated with ice in the winter time. Very different opinions have been expressed, and various is the practice, with regard to the amount of slope allowed in a footpath. Peter Nicholson and Henry Law, for example, say that 1 in. in 10 ft. is sufficient slope in a paved footpath. Codrington says a slope of 1 in 30 (1 in. in 2 ft. 6 in.) should be given. Boulnois says, "for natural stones, about $\frac{1}{4}$ in. to the foot is usually given, but for concrete or asphalt footways $\frac{1}{8}$ in. to the foot is sufficient." Perhaps the best authority is the Model Bye-laws, which suggest that "the footpaths shall be constructed so as to slope or fall towards the kerb or outer edge at the rate of $\frac{1}{2}$ in. in every foot of width if the footway be not paved, flagged, or asphalted; and at the rate of not less than $\frac{1}{4}$ in. and not more than $\frac{1}{2}$ in. in every foot of width if the footway be paved, flagged, or asphalted."

Fig. 30.—Section of Drained Footpath.

Gravel footpaths are suitable only for country districts where the traffic is very light. They are formed by a layer of gravel, either with or without special foundations. Where the natural formation of the ground is sandy or gravelly, no special preparation may be necessary, but, in other cases, there must be a foundation that will be sufficiently porous to drain away any water. Furnace clinker, ashes, broken brick, or other hard ballast, should be laid to a depth of 6 in. or 9 in., and in this, if it

is wished to have the path specially well drained, agricultural drain pipes may be embedded. The top coating of gravel should be from 4 in. to 6 in. in thickness, finished with fine screened gravel, mixed with a little loamy earth as a binding material, and well rolled.

Fig. 30 shows a section of a path of the above kind, suitable for a width of about 3 ft. After laying the drain pipes at the bottom of the trench, they should be covered over with sods of turf, laid with the grassy side downwards, or with small brushwood, to prevent the joints from being filled.

Fig. 31.—Section of Gravel Footpath.

Above this a little earth is laid, then the ballast, and last of all the fine gravel. Fig. 31 illustrates a section of a gravel footpath which has been recently constructed in a public park. The path is 6 ft. wide, and more than a mile long, the excavation to take the ballast being 15 in. deep. The foundation is 9 in. in thickness, and is formed of broken bricks, coarse gravel, or other approved material, broken to pass through a 2½-in. gauge, and then well rolled with a horse roller weighing 15 cwt. The upper layer is 6 in. in thickness, formed of smaller gravel to ½-in. gauge, and well rolled with a 15-cwt. roller. A 3-in. open-jointed drain is laid along the centre of the whole length of the walk, below the bottom of the foundation, as shown in the illustration.

The tarring of gravel paths is resorted to occasionally, but the path must previously have been thoroughly consolidated. Tarring must be done only when the weather is quite settled and fine, as the least rain will spoil it. The surface of the path is tarred over in exactly the same manner as a wall would be tarred, and immediately the operation is completed fine stone should be sprinkled over the surface. The traffic should be diverted for a few hours, after which the path will be ready for use.

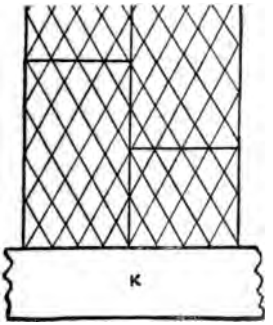


Fig. 32.

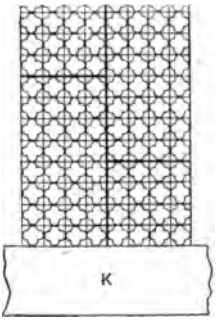


Fig. 33.

Figs. 32 and 33.—Diamond Pattern and Rosette Pattern Brick Pavements.

The tar should be of good consistence, but should not be applied to form a very thick coat.

Stone setts make a very common form of footpath for use in country towns. The setts are 4 in. or 5 in. square, and of the same kind as those used in street paving. These paths are apt to be very uneven in their general surface, and the numerous joints between the stones afford a resting-place for dirt. In fine weather such paths are not so pleasant to pedestrians as a well-flagged path, but in winter, when the paths are coated with ice, they give a better foothold than the slippery flags.

Brick-paved footpaths are very general thro'

out many parts of England, and there is much to be said in their favour. Bricks are easily laid, and are easily removed when it is necessary to lay or repair gas-pipes or water-pipes, or to make connections with house drains. Bricks are comparatively cheap, and are not unpleasant to walk on, giving a better foothold in winter than a smooth flagged or asphalted pavement. The dark colour of the Staffordshire blue brick is objected to by some persons, but it is certainly to be preferred, under a glaring sun, to the light colour of a flagged pavement, which reflects the sunlight up into the eyes. When laid with a broad stone coping, bricks are decidedly neat in appearance. The objections to brick pavements are that, like all pavements with many joints, they cannot be kept so clean as asphalt, tar-paving, or monolith cement paving. They are also apt to sink locally, forming hollows; and when the bricks are not sufficiently burnt, the outer surface wears off and shows the interior red colour of the brick. The sizes in use are very numerous, including such sizes as 12 in. square, 10 in. by 5 in., $8\frac{3}{4}$ in. by $4\frac{1}{4}$ in., 9 in. by 5 in., and 7 in. by $4\frac{1}{2}$ in. The thickness also varies from $1\frac{1}{2}$ in. to 3 in.

In America, ordinary plain-faced bricks are used for footpaths, but in England they are usually ornamented; examples of ornamentation are the diamond pattern (Fig. 32) and the rosette pattern (Fig. 33). The hardest bricks are made of blue Staffordshire vitrified stoneware, but red and buff bricks are obtainable, and are useful for forming ornamental panels in spaces before shops which are set back from the line of footpath, round central lamps, or in similar positions. As a rule they are laid in straight courses across the line of the footpath, as indicated in Fig. 32, but in some towns they are laid in herringbone fashion, as shown in Fig. 34. In Figs. 32 to 34, K shows the kerb.

As to the foundations and the manner of laying the bricks, there is, again, much diversity of practice. Sometimes a concrete foundation is prepared, on which the bricks are bedded on a thin layer of cinders or sand; sometimes hard ballast is used for the foundation. As exemplifying the various methods adopted, the following particulars supplied by a number of town surveyors will be found useful. At Acton, blue chequered Staffordshire bricks, 9 in. by 5 in., are laid and jointed in lime mortar on a foundation of broken clinker. At Ashby-de-la-Zouch, blue Staffordshire bricks, 9 in. by 4½ in. by 3 in., are laid on a foundation of broken

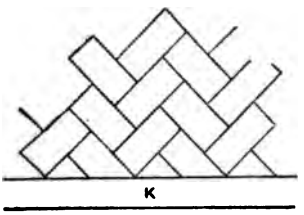


Fig. 34.—Herring-bone Pattern Brick Pavement.

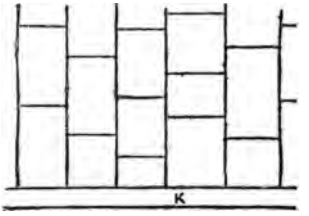


Fig. 35.—Disposition of Flags in Footpath.

bricks and engine ashes, and jointed with sand. At Barmouth, blue bricks, 7 in. by 4½ in. by 3 in., are laid on broken stones or concrete, and grouted with cement. At Beckenham, Burgess Hill red bricks are used, 8¾ in. by 4¼ in. by 2 in., on 4 in. of hard core and 3 in. of Portland cement concrete, jointed with lime grout and sharp sand. At Bedford, blue Staffordshire bricks, 10 in. by 5 in. by 2 in., are laid in mortar on a bed of sand on gravel foundations. At Birmingham, blue bricks, 10 in. by 5 in. by 2½ in., are laid in mortar on a foundation of 6 in. of ashes. At Chester, Staffordshire and Buckley bricks, 12 in. to 9 in. by 4 in. by 2 in., and 12 in. square, are laid in mortar on ordinary

soil or sand bedding. At Crewe, Staffordshire blue bricks, 9 in. by 4½ in. by 2¼ in., are laid herringbone on a foundation of fine cinders 6 in. thick, covered by a layer of sand 1 in. thick, and jointed with sand. At Derby, Staffordshire blue bricks, 9 in. by 4½ in. by 2 in., are laid on a foundation of 5 in. of ashes and ½ in. of sand, and are jointed with dry sand. At Dorchester, Staffordshire blue bricks, 10 in. by 5 in. by 2½ in., are laid on 4 in. of cement concrete with a bedding of ½ in. of sand, and jointed with dry sand. At Dudley, Staffordshire blue bricks, 12 in. by 6 in. by 2 in., and 10 in. by 5 in. by 2 in., are bedded and jointed in mortar on a foundation of 6 in. of furnace ashes. At East Ham, blue Staffordshire bricks, 10 in. by 5 in. by 2 in., are laid in fine sand on a foundation of ashes upon clay, and grouted with Portland cement and sand in the proportion of 1 to 1. At Finchley, blue Staffordshire bricks, 10 in. by 5 in., white Poole, 9 in. by 4½ in., and red Tunbridge, 9 in. by 4½ in., are laid on 3 in. of Portland cement concrete and grouted with cement. At Gloucester, Staffordshire blue bricks, 12 in. by 6 in. by 2 in., are bedded in mortar on 4 in. of brick rubble and 1 in. of gravel and sand, and are jointed with mortar. At Hanley, blue Staffordshire bricks, 9 in. by 4½ in. by 2¼ in., are laid herringbone on a foundation of engine ashes and jointed with ashes and sand. At Hereford, blue brindled bricks and blue Staffordshire chequered, 9 in. by 4½ in. by 2 in., are laid on a foundation of concrete and jointed in cement; the brindled bricks are laid on their edge. At Keswick, blue Staffordshire bricks, 10 in. by 5 in. by 2 in., are bedded on dry sand on a foundation of 3 in. of sand and gravel, and are grouted with cement. At Littlehampton, Staffordshire and Buckley blue clinker bricks, 9 in. by 4½ in. by 2 in., are laid in lime mortar on 4 in. of concrete, and jointed in mortar, and grouted with liquid cement.

At Newton-in-Makerfield, blue Staffordshire chequered bricks, 11 in. by 5½ in. by 2 in., are laid on a foundation of brickbats and red sand, and jointed in mortar. At Okehampton, Candy's plain buff vitrified bricks, 9 in. by 4½ in. by 2 in., are laid in thin mortar on a foundation of lime concrete 3 in. thick, and grouted with cement. At Oxford, blue Staffordshire bricks, 10 in. by 2 in., are laid on a bed of lias mortar with a foundation of gravel and gas ashes, and are then jointed with good lias mortar. At Portsmouth, vitrified blue bricks, 9 in. by 4½ in. by 2½ in., are laid with mortar on a gravel foundation, and are jointed with mortar. At Runcorn, bricks of Buckley and Staffordshire make, 12 in. by 6 in., and 9 in. by 4½ in., are laid on a screened bed of sand and cinders, and jointed with sand. At Sleaford, blue Staffordshire bricks, 9 in. by 4½ in. by 2½ in., are laid in cement on a foundation of cement concrete, and jointed with cement. At Stourbridge, blue bricks, 10 in. by 5 in. by 2 in., are bedded in mortar on a foundation of ashes. At Tynemouth, the bricks are laid on a 6-in. foundation of concrete, composed of one part cement to eight parts sand and gravel, bedded on sand and jointed with pitch. At West Bromwich, blue Staffordshire bricks, 10 in. by 5 in. by 2 in., are laid on a foundation of ashes and ballast, and jointed with fine engine ashes swept into the joints. At West Hartlepool, blue Staffordshire bricks, 10 in. by 5 in. by 2½ in., are bedded in lime mortar on a foundation of 3 in. of sand and ashes, and jointed with sand. At Wimbledon, bricks of the Buckley, Candy, and blue Staffordshire varieties, 10 in. by 5 in. by 2 in., and 9 in. by 4½ in. by 2 in., are laid dry on a foundation of ashes, and grouted with sand and water.

Bricks made from blast-furnace slag are much used for paving in certain districts, particularly in

the North of England, where ironworks abound. Slag is the refuse from the smelting of iron ore in the production of pig-iron, and although some millions of tons of this waste material are produced annually in the North of England, it has only been within the last thirty years or so that any use for it has been found, other than in ballasting for roads or in the formation of breakwaters.

The making of bricks by Woodward's process is a very simple matter. The slag is run direct from the furnace into moulds, of any desired form or size, which are placed on a turntable, movable by hand or power, and brought in turn under the spout from which the molten slag flows. A crust soon forms over the slag; the moulds, which are of iron and hinged, open and the blocks fall out and are taken to the annealing oven, where they are subjected to a white heat for twenty-four hours. They are slowly cooled, and the bricks are then ready for use. They are well moulded, square and sharp on the edges, and very neat in appearance. They are made of various sizes, these including: 5 in. deep by 9 in. by 4 in.; 6 in. deep by 8 in. by 3½ in.; and 7 in. deep by 7 in. by 3½ in. To lessen the objection to their smooth surface and close joints, a chamfer is usually formed round the top face of the brick, thus affording a foothold.

The flagstones used for footpaths are usually the so-called York flagging, much of which comes from Lancashire. Slates are also used to a slight extent, and so is granite. The latter is naturally too expensive in first cost and in manipulation to be much used, and is also too slippery to be much in favour as a material for footpaths. Slate is subject to the same disadvantage, and even in the towns of North Wales, where the slate is cheap, flagstones are preferred for the best work.

The flagstones of Yorkshire and Lancashire are obtained from the Millstone Grits and Coal

Measures of the Carboniferous formations. They vary in quality according to the quarries from which they are taken; but excellent flags are to be had from the neighbourhood of Burnley and Wigan, in Lancashire, and Elland, in Yorkshire. In Scotland, good flags are obtained from Cromarty, Nairn, and Caithness. The Caithness flagstone is very hard, compact, and close-grained, occurring in beds of from 1 in. to 9 in. thick in the Old Red Sandstones of the district. It does not scale in wear, is very durable, and is not affected by frost.

All sandstones are naturally porous and absorb water, which they retain for a long time. In the

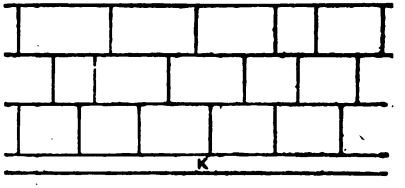


Fig. 36.—Disposition of Flags in Footpath.

winter time the water so retained freezes and splits off some of the upper laminations in the softer stones, thus tending towards their destruction. This, and the varying hardness of the stone, makes the softer kinds of sandstone pit and wear badly.

The sizes of the separate flagstones affect the appearance of a footpath, large flags giving a smoother and pleasanter path, but costing more than small ones. The sizes actually in use vary greatly in different districts; thus, in Bradford, Yorkshire, 3 sq. ft. is the minimum area allowed in any one stone. In Blackburn, 5 sq. ft. is the minimum area. Very often the practice is to specify a certain gauge or width of flag, and then a maximum and minimum length; thus, at Stockton-

on-Tees, the gauge may be either 24 in., 30 in., or 36 in., while the length must be not less than 15 in., and the average length of all the flags not less than 20 in.

The usual manner of disposing the flags in the footpath is with the gauge or regular width running across the direction of the path, as shown in Fig. 35, but this system is not invariably followed, the gauge being sometimes disposed as in Fig. 36. The gauge or width of the courses is generally from 2 ft. to 3 ft.

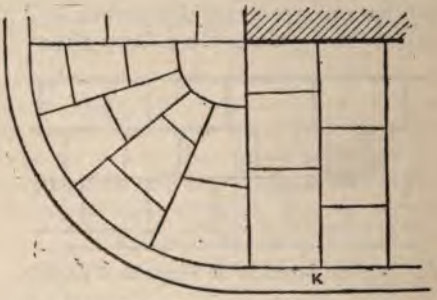


Fig. 37.—Path Flags at Street Corner.

The foundation on which flags are laid consists generally of a 3 in. or 4 in. thickness of cinders or gravel, and the flags are bedded solidly on this, driven into place with a heavy mallet, and the joints flushed up with mortar and afterwards pointed. It is important to square carefully the edges of the flags, so as to make a neat-fitting joint, without undercutting in a fashion that would weaken the flag at the edge. The footpath is laid with a slight fall at the kerb K (Figs. 35 and 36) so as to clear itself of water, the inclination being usually $\frac{1}{2}$ in. to each foot of width. At corners of streets, in the best work, the flags are radiated in the manner shown in Fig. 37; in commoner work

the courses are run through, as shown in Fig. 38. In these figures, K indicates the kerb.

Concrete paving for footpaths has certain advantages. In districts where flagstones for footpaths were difficult to obtain, attention was naturally directed to concrete as a substance that might be used in place of the more expensive material. The concrete is made by embedding stones, broken bricks, or other hard substances, in a mass of lime or cement mortar, and it has been found that a thin layer of it was easily laid, and

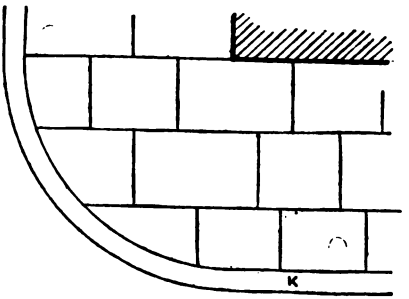


Fig. 38.—Path Flags at Street Corner.

possessed many advantages over some other forms of paving; but serious drawbacks were the difficulty of repairing it after it had been broken up for the purposes of laying drain or gas or water pipes, and the impossibility of laying it in frosty weather. Because of these and other considerations, instead of laying the concrete in one mass, the usual plan now is to prepare concrete slabs or artificial flagstones, and to lay them in exactly the same way as natural flagstones are laid.

Monolith concrete, or concrete laid over large surfaces of the path in one mass in the position it is to occupy, is still used. Foundations should be provided, and may be composed of clinker or brick

rubbish. Sometimes a bottom layer, 1 in. in thickness, is formed of cinders or gravel, followed by a layer of clean, hard stone broken to 3-in. gauge. The foundations are brought up to within 2 in. of the required level of the footpath. As a large surface of concrete of only 2 in. in thickness would not stand the changes of temperature without cracking, it is always laid in bays or panels of 5 ft. or 6 ft. in width, the partitions being thin strips of wood, 2 in. deep and $\frac{1}{4}$ in. thick, which are laid across the footpath at the proper level, and serve not only to form the divisions of the panels, but as screeds for regulating the surface levels. The concrete to form the pavement is then filled into each alternate panel, and, when they are set hard and firm, the intermediate panels are filled in, thus avoiding the cracking or uprising of the pavement from expansion of the concrete. The strips of wood are in some cases left embedded in the concrete; occasionally iron strips are used, and replaced by wooden strips after the concrete is laid.

A suitable concrete is composed of 1 part by measure of Portland cement, 2 parts of coarse, clean gravel of 1-in. gauge, and 2 parts of clean, sharp sand. The concrete should be well rammed after being deposited in position, and, before it is set, a finishing coat of a finer and richer concrete, 1 in. in thickness, should be laid and finished to a smooth surface. This finishing coat usually contains 1 part of Portland cement to 2 parts of granite chippings or fine, hard gravel.

A concrete used by C. H. Cooper in laying some 13,000 sq. yd. of footpath, consisted of Guernsey granite chippings and cement; it was deposited in two layers, the first being $1\frac{1}{4}$ in. thick, composed of chippings that passed through a $\frac{3}{4}$-in. mesh, and were retained on a $\frac{3}{16}$-in. mesh, mixed with cement in the proportion of 4 parts of chippings to 1 part

of cement. The top layer was $\frac{3}{4}$ in. thick, composed of 1 part of cement to 2 parts of chippings of $\frac{3}{16}$-in. gauge. This top layer was placed on the bottom layer within half an hour after the latter was laid. All the materials used should be as clean as possible, and the cement should be finely ground and cool.

The freshly laid work should be protected from the rays of the sun by covering it with cloths, and in dry or hot weather the panels should be kept constantly wet, in order to delay as long as possible the setting of the concrete, so that its full strength may be developed. Traffic must not be permitted on the path for at least a week, and preferably for a fortnight. Most of the makers of artificial paving slabs are prepared to lay monolith pavements on their special systems, but, for the reasons already mentioned, the separate slabs offer several advantages over the monolith system.

The much used concrete flags or paving slabs are made by moulding concrete in iron or wooden moulds, with or without pressure. The Portland cement should be of specially good quality, and in order that it may be well matured it is usual to specify that it shall be delivered at the manufactory at least a fortnight before it is required for use. Granite, broken to the size of pea gravel, that is to say, such as will pass through a $\frac{3}{16}$-in. gauge, is mixed with the cement in the proportion of three or four parts of gravel to one part of cement, and water is added in very small quantities while the mixing is going on, until the whole is thoroughly incorporated. As little water as possible should be used. The concrete is then placed in the moulds, which have been previously coated with soft soap to prevent the mixture sticking to them. To ensure sharp corners and arrises to the slabs it is well to line the moulds with sheet-iron. The concrete is rammed well into the corners, etc.,

is trimmed off to a fair face level with the top of the mould, and then left undisturbed for a few days until sufficiently set to be handled. The slab is then taken off and stored away to mature in order to bring out the full strength of the cement. The setting should not be allowed to proceed too rapidly, and the slabs should not be used for paving until they are three or four months old.

When pressure is used to consolidate the concrete, iron moulds, provided with iron covers, giving two fair faces to the slabs, are used. Greater strength is obtained by subjecting the material to pressure, and in some towns the municipal authorities find it possible to utilise in this way the clinker from the destructor furnaces, the clinker taking the place of broken granite. These slabs, when laid on a bedding of sand or ashes, on which has been spread a layer of lime mortar, make an excellent footpath. The joints, which should be grouted with lime mortar, can be made very fine, and as the slabs are uniform in size, all the joints are disposed in straight lines, and present a pleasing appearance.

The Jones annealed concrete slabs, made in Middlesbrough, are largely used in Northumberland, Durham, and Yorkshire, as well as, to a smaller extent, in other parts of the country. These slabs are made from slag blocks, which are manufactured as described on p. 80. The slag blocks are crushed by machinery, mixed with Portland cement, and then, with the addition of water, thoroughly incorporated in a pug mill. The plastic material is finally placed in moulds, and allowed to set in the usual manner. The flags are made of two thicknesses (2 in. and 2½ in.), and all of them are 2 ft. in width. The lengths stocked by the manufacturers range from 1 ft. 6 in., increasing by 3 in., up to 3 ft. long. One ton of 2-in. flags will cover 10½ sq. yds. of path, and a ton of 2½-in. will cover

9½ sq. yds. In some tests of the strength of these slabs carried out by Messrs. Kirkaldy and Son, in December, 1896, the slabs broke with pressure of from 3,569 lb. to 4,005 lb., distributed over an area of 4 sq. ft. These experiments were on samples taken from a consignment of slabs intended for actual use.

Patent indurated stone, originally introduced in 1885, is made from crushed Leicester granite mixed with Portland cement and moulded in steel-lined moulds. The slabs are then hardened by a chemical process and stocked to mature; maturing ordinarily occupies six to nine months. Slabs of 2 in., 2½ in., and 3 in. in thickness are stocked by the makers, all being 2 ft. wide and from 2 ft. to 3 ft. 6 in. long. The crushing strength of patent indurated stone was certified by Mr. David Kirkaldy to be 7,134 lb. per cubic inch, which is equal to, or greater than, the strength of granite.

Patent Victoria stone has been in use as a paving material for between thirty and forty years. At the International Building Trades Exhibition, Islington, in March, 1897, a slab of this artificial stone was exhibited which had been laid in 1882 at the South Kensington Exhibition. The traffic over it during four exhibitions would amount to some twenty million persons, yet the stone was only worn to the extent of about $\frac{1}{32}$ in. The principal constituents of Victoria stone, as of most artificial stones, are granite and Portland cement, but other special processes form a part of the manufacture. The most important of these depends upon the addition of fluid silicates to the composition of which the slabs are made. Some years ago the Rev. William Heighton, experimenting on a stone containing 70 to 90 per cent. of silica, reduced it to powder and treated it with caustic soda. Boiling the two together with water, he obtained a fluid silicate, or what may be called a solution of flin-

This invention was acquired by the Victoria Stone Company, and utilised by them in producing their extremely hard artificial compound. The granite, after being freed from alumina and ground to a fine powder, is mixed with one-third of its bulk of Portland cement and incorporated by the addition of a small quantity of water. The mixture is then placed in metal-lined moulds in the usual way. When taken from the moulds the slabs are steeped in tanks containing the siliceous solution which permeates the porous body of the concrete, setting into a hard, flinty mass and rendering the slab extremely strong and impervious to water.

Victoria stone forms a very durable pavement; it is laid on London Bridge, where 126,000 foot passengers cross every day. At Blackfriars Bridge, too, the Victoria pavement, laid in 1869, still remains, although subject to a very heavy traffic. In some cases, as in Islington, the slabs that have been laid for some years have been taken up and immediately replaced upside down. Victoria stone was tested by Mr. David Kirkaldy, and its resistance to crushing was found to be 8,321 lb. per cubic inch, whereas the strength of Peterhead granite is usually taken at about 6,200 lb. per cubic inch. The slabs are made 2 in. thick, all being 2 ft. wide, and varying in length from 1 ft. 6 in. to 3 ft. They are also made 3 in. thick, 2 ft. wide, and in lengths varying from 2 ft. to 4 ft.

Stuart's granolithic is well known, some hundreds of miles of pavement having been laid on this system. Its durability is excellent. Some slabs of this material, after having lain in Leadenhall Street, London, for about eleven years, were tested by Messrs. Kirkcaldy and Son. The test pieces measured 3 in. square by approximately 1½ in. thick, and a pressure of 562 tons per square foot was sustained before the material was crushed. Other experiments on the strength of slabs of this de-

scription showed that 2-in. slabs 2 ft. in width, when resting on supports 2 ft. apart, sustained before breaking a load of 19 cwt. 1 qr. 17 lb.

Imperial stone may also be mentioned. It has been extensively used by the Metropolitan Board of Works and the authorities of many districts and parishes in the neighbourhood of London, as well as in many towns in the South of England.

Tar paving, which is often, though erroneously, called asphalt, is an attempt to obtain with cheap materials the natural advantages of real asphalt. Asphalt, as stated in Chapter V., is composed almost entirely of limestone saturated with natural bitumen, and the substitutes which have been designed to take its place are mostly composed of mixtures of limestone chippings, broken granite, or gravel, with gas tar and a small proportion of other ingredients, pitch, resin, or creosote oil (see p. 26). Although no such composition can compare in durability with natural asphalt, tar paving forms a very useful and economical covering for footpaths, and is much used.

The mode of preparing tar paving for footpaths is briefly as follows: Small stones are thoroughly dried and heated and mixed with gas tar, which is allowed to soak into the substance of the stone; this composition is then laid on the foundation and well rolled. The details of the process vary slightly in different districts. One of the earliest mixtures, known as Lord Stanhope's composition, consisted of 30 gallons of Stockholm tar mixed with 20 bushels of chalk and 10 bushels of clean sharp sand; these were all boiled together in cauldrons, and laid while hot to form the surface of the footpath.

Good foundations are essential in this as in any other kind of paving. Hard ballast, cinders, or broken stone 3 in. or 4 in. thick should be laid and well consolidated by rolling. To economise material, the surface of the foundations should be

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brought to the exact level required, and to the slope required on the finished surface of the path. This slope may be ¼ in. for every foot of width. On the foundation is laid the bottom coat of tar paving, which may be from 1½ in. to 3 in. thick, according to local requirements.

In one of the simpler methods of preparing this bottom coating, the gravel or chippings of the required size, usually not greater than 2-in. gauge and sometimes as small as 1¼-in. gauge, are laid on a heap of about 1 ft. thick. Several fires are made on the top of the heap and are covered down with refuse cinders to cause the heat to strike downwards and completely evaporate all moisture from the stone. When the heap is covered with cinders and is one mass of fire, it is then turned over with a shovel and sprinkled with gas tar, the process being repeated until the whole of the stone has received a sufficient coating of tar. It is allowed to lie for some weeks, so that the tar may thoroughly soak into the stone, when it is laid on the foundations to the required thickness, which may be anything from 1½ in. to 3 in. ; and, in fact, this amount of variation is found in the stipulations of the street specifications of different towns. The bottom coating is then well rolled, and in places where the roller cannot be applied it is rammed.

Sometimes the remainder of the material is added in two coats, but usually one is sufficient. This, known as the topping, is, in some cases, a mixture of fine ashes and gravel or chippings, the whole being passed through a ⅜-in. wire riddle. The ashes are laid on the ground to a thickness of 6 in., with 6 in. of gravel or chippings on the top, and heated by fires in the same way as in preparing the bottom coat. The tar is then added as before described, and the material, after storing, is ready for use. It is usually laid in a thin coat, say from ⅝ in. to 1 in. in thickness, and must be well rolled.

When the surface is finished, a sprinkling of very fine limestone chippings is spread over it and well rolled in.

The methods of drying and heating the material are various. E. P. Hooley's system adopted in forming footpaths in the rural districts of Nottinghamshire, is to lay four sections of ordinary 4-in. glazed pipes in the form of a cross, leading to a central upright section of pipe which forms a chimney. Faggots and breeze are laid round the pipes, and, when well alight, the material is gradually deposited in a cone-shaped heap and is allowed to dry slowly. When thoroughly dry, and warm enough to allow the hand to be held on the surface without discomfort, it is saturated with the tar mixture, which has been boiling while the heap has been drying. Mr. Hooley's mixture is 40 gal. of tar, 28 lb. of pitch, 20 lb. of Portland cement, and 6 lb. of resin. Another well-known mixture consists of 12 gal. tar, ½ cwt. of pitch, and 2 gal. of creosote, these forming the quantity required for one ton of chippings or gravel. It is essential that the stone should be sufficiently heated to absorb the tar properly, a mere coating of tar not being sufficient; and this absorption will not take place unless the stone is perfectly dry before the tar is applied.

The storing of the tarred material for a month or two (some surveyors recommend at least three months) assists in obtaining this thorough saturation. The laying of the footpath should be undertaken in cool and dry weather, and it is important to remember that it is impossible to roll the footpath too much. The roller should be about 2 ft. 3 in. wide, should weigh about 12 cwt., and should be provided with rounded edges which will not leave ridges on the surface of the path. If the tarred material sticks to the roller, the latter may be dressed with oil three or four times a day, or a

spray of water may be arranged to play continually on the face of the roller.

Tar paving lasts from five to twenty years, according to the quality of the materials, the workmanship, and the amount of traffic passing over it. To maintain such paths in good condition it is advisable to give them, every second or third year, a coating of tar with a sprinkling of the fine spar used as a finishing coat. Any defective portions can be cut out and replaced with new material.

With regard to real asphalt footpaths, the composition of natural asphalt and its use as a material for covering carriageways are described at length in Chapter V. Very little remains to be added to the details there given, as the application of asphalt to footpaths is almost identical with the process there described. For carriageways, both compressed and mastic asphalts are used. A concrete foundation, 2 in. or 3 in. in thickness, is usually provided, and on this the asphalt is laid in the manner already described, but while a layer of 1½ in. to 2 in. is considered necessary for carriageways, footpaths do not require a greater thickness than ½ in. to 1 in .of mastic asphalt, or 1 in. to 1½ in. of compressed asphalt.

Asphalt, as has been pointed out, is extremely durable, and forms a cleanly and pleasant path. It is, however, slippery under some conditions, and if laid on steep inclinations it has a tendency to creep, developing cracks which increase in size.

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